Defense Advanced Research Projects Agency

Strategic Plan

May 2009

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DARPA's Strategic Plan

1. Purpose

This document describes the Defense Advanced Research Projects Agency's (DARPA) strategy, as required by Section 2352, Title 10 of the United States Code. It provides a top-level view of DARPA's activities for Congress, the research community, and various elements of the Department of Defense (DoD).

This strategic plan describes DARPA's mission, business processes, research thrusts and objectives, and research projects to achieve the objectives.

2. DARPA

2.1. Mission, Management, and Organization

DARPA's original mission, inspired by the Soviet Union beating the United States into space with Sputnik, was to prevent technological surprise. This mission has evolved over time. Today, DARPA's mission is to prevent technological surprise for us *and* to create technological surprise for our adversaries. Stealth is one example of how DARPA created technological surprise.

DARPA's strategy for accomplishing its mission is embodied in strategic thrusts. Over time, as threats and opportunities change, DARPA's strategic thrusts evolve. Today there are nine strategic thrusts, detailed in Section 3, that are key national security research areas building the foundations for innovative joint warfighting capabilities to defeat existing and emerging national security threats.

DARPA's main tactic for executing its strategy is to constantly search worldwide for revolutionary high-payoff ideas and then sponsor projects that bridge the gap between fundamental discoveries and new military capabilities.

DARPA's mission implies one imperative for the Agency: radical innovation for national security. DARPA's business processes reflect this in a straightforward way: bring in expert, entrepreneurial program managers; empower them; protect them from red tape; and quickly make decisions about starting, continuing, or stopping research projects.

To maintain an entrepreneurial atmosphere and the flow of new ideas, DARPA hires program managers for only 4 to 6 years because the best way to foster new ideas is to bring in new people with fresh outlooks. New people also ensure that DARPA has very few institutional interests besides innovation. New program managers are willing to redirect the work of their predecessors – and even undo it, if necessary. Since program managers are not at DARPA for a career, they are willing to pursue high-risk technical ideas even if there is a reasonable chance the idea will fail. Another element of DARPA's strategy is to cultivate entrepreneurial performers in universities and industries by funding ideas that represent revolutionary technical achievements.

Another unique feature of DARPA is that the Agency has very limited overhead and no laboratories or facilities. Again, the idea is to minimize any institutional interests that might distract the Agency from its imperative for innovation, or make it wedded to a particular set of technologies.

DARPA's current organizational structure is shown in Figure 1. This chart implies more formal structure than is actually the case at DARPA. In general, the character and mission of DARPA offices change over time as threats to U.S. national security and technological opportunities change. Offices are fluid and are created and disbanded as appropriate to keep DARPA's organization forward-looking, relevant, and responsive to new opportunities.

DARPA has found that physically co-locating experts with similar or complementary interests leads to enhanced generation of entrepreneurial ideas. The office directors recruit outstanding program managers and develop the office synergy, while keeping the program managers broadly on track with the office theme.

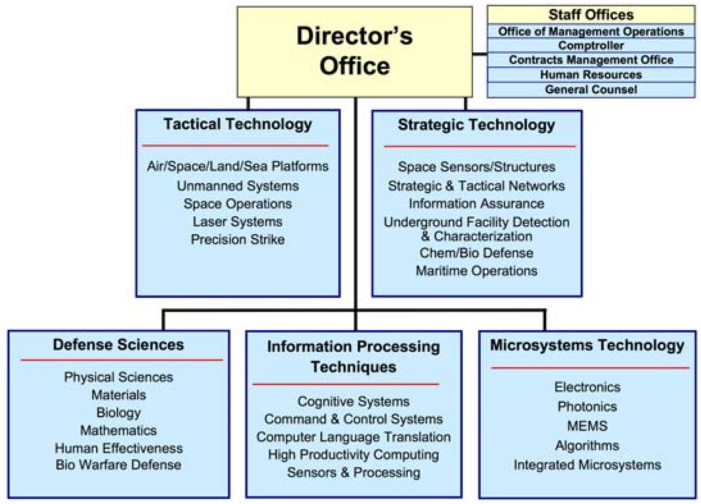

Figure 1: DARPA's organization.

The themes of each office are derived from DARPA's strategy and set by the DARPA Director as a result of assessments of technical advances worldwide and interactions with the Secretary and Under Secretaries of Defense, Chairman of the Joint Chiefs of Staff, Combatant Commanders, Service Secretaries, Service Chiefs, Service units, and the staffs at each DoD level.

There are two basic types of technical offices at DARPA: technology offices and systems offices. The technology offices focus on new capabilities and component technologies that might have significant national security applications. Currently, these offices are the Defense Sciences Office and the Microsystems Technology Office. The systems offices focus on solutions to military problems and technology programs leading to products that more closely resemble a specific military end-product; i.e., an item that might eventually be in the military inventory. These offices are the Tactical Technology Office and Strategic Technology Office. And one office, the Information Processing Techniques Office, has some characteristics of *both* the technology and systems offices. As a practical matter, a fair amount of overlap exists between the two types of offices: the work in the technology offices often shapes the work of the systems offices, and vice versa.

In addition to the technical offices, DARPA has staff offices that support overall agency operations: Office of Management Operations, which includes facilities, information resources, and security; Comptroller, which oversees financial matters; Contracts Management, which provides in-house contracting; Human Resources, which recruits and retains staff; and General Counsel, which provides legal advice.

Congress has granted DARPA authorities to assist the Agency in carrying out its unique mission in accordance with its flexible management philosophy. DARPA has an Experimental Personnel Authority that allows it to maintain its entrepreneurial edge by hiring expert program managers from industry at competitive salaries, and doing it much faster than under normal Civil Service rules.[1] DoD, as a whole, now has a similar authority modeled on DARPA's authority, and DARPA is also making use of it.[2] And DARPA uses Other Transactions Authorities, which allow alternative contracting arrangements than the Federal Acquisition Regulations.[3]

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1 5 USC 3104 Note

2 5 USC 9903

3 10 USC 2371 and 10 USC 2371 Note

2.2. DARPA's Role

DARPA is a Defense Agency with a specific role within DoD. DARPA is not tied to a particular operational mission: DARPA supplies technological options for the entire Department, and is designed to be a specialized "technological engine" for transforming DoD.

Near-term needs and requirements generally drive the Army, Navy, Marine Corps, and Air Force to focus on those needs at the expense of longer-term changes. Consequently, a large organization like DoD needs a place like DARPA whose *only* charter is radical innovation.

DARPA looks beyond today's known needs and requirements. As military historians note, "None of the most important weapons transforming warfare in the 20th century – the airplane, tank, radar, jet engine, helicopter, electronic computer, not even the atomic bomb – owed its initial development to a doctrinal requirement or request of the military."[4] *None* of them. DARPA would add to this list unmanned systems, stealth, and the global positioning system (GPS), which was preceded by a DARPA system called Transit, and Internet technologies.

DARPA's approach is to imagine what capabilities a *future* military commander might need and accelerate those capabilities into being through technology demonstrations. These could not only provide options to the commander, but also change minds about what is technologically possible today and how current and future objectives could be met. DARPA often "works the seams" among the military Services to develop new and truly joint capabilities that no military Service could support by itself.

Figures 2 and 3 illustrate how DARPA works. These figures show where science and technology (S&T) funding is invested along a notional timeline from "Near" to "Far," which is indicative of the "time to go" for an S&T investment to be incorporated into an acquisition program.

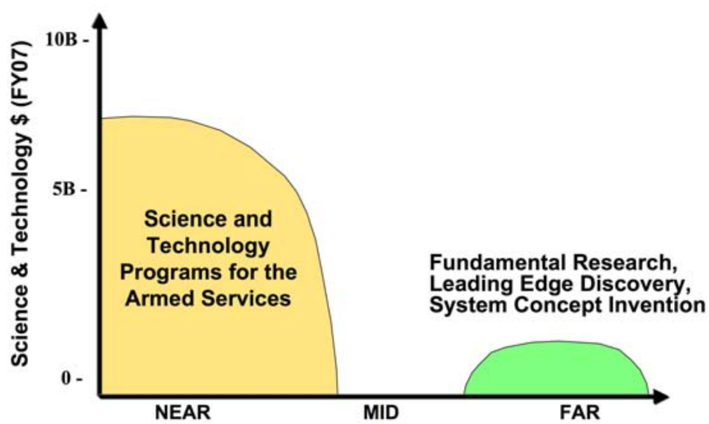

Figure 2: Timelines and investments in science and technology.

The Near bubble in Figure 2 represents most of the work of the Service S&T organizations. Service S&T tends to gravitate toward the Near side because the Services emphasize providing technical capabilities critical to the mission requirements of *today's* warfighter. This is excellent and crucial S&T because it continuously hones U.S. military capabilities, e.g., improving the efficiency of jet engines and making existing radios more reliable. It is typically focused on known systems and known problems.

The Far bubble in Figure 2 represents fundamental discoveries where new science, new ideas and radical new concepts typically first surface. People working on the "Far side" have ideas for entirely new types of devices or new ways to put together capabilities from different Services in a revolutionary manner. But the people on the Far side have a difficult, sometimes impossible

4 John Chambers, ed., *The Oxford Companion to American Military History* (New York: Oxford University Press, 1999) p. 791.

time obtaining funding from those on the larger Near side because of the Near side's focus on improvements against current, known problems.

Whenever there have been technological surprises, the people surprised typically are on the Near side. There are always people on the Far side who believed that something could be done, but they were not able to obtain the needed resources. The Soviets beating the U.S into space with Sputnik in 1957 is a prime example. Sputnik motivated President Eisenhower to create DARPA in 1958 to bridge the gap between these two groups.

DARPA's mission, shown in Figure 3, is to find the people and ideas on the Far side, and accelerate those ideas to the Near side as quickly as possible.

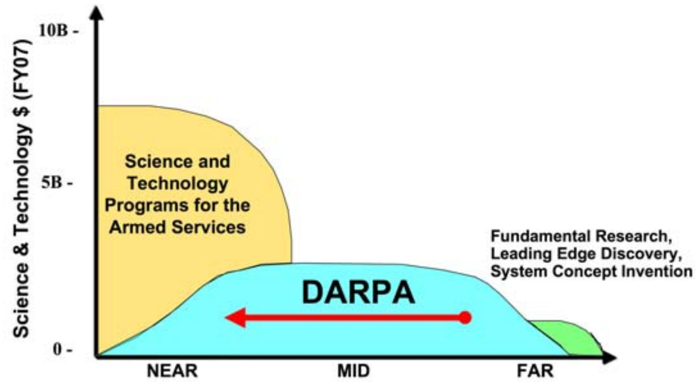

Figure 3: DARPA's role in science and technology.

These new capabilities often stem from developments at the component technology level, such as those promoted by DARPA's Core Technologies thrust (Section 3.9). Hence, DARPA mines fundamental discoveries – the Far side – and accelerates their development and lowers their risks until they prove their promise and can be adopted by the Services. DARPA's work is high-risk and high-payoff precisely because it bridges the gap between fundamental discoveries and their military use. Even though much of DARPA's work takes years to reach payoff, DARPA's flexibility and ability to change direction quickly allow it to react swiftly to emerging threats during a conflict. The inset discussion, "Shaping DARPA's Strategy" (p. 5) provides a more detailed discussion of how DARPA chooses its programs.

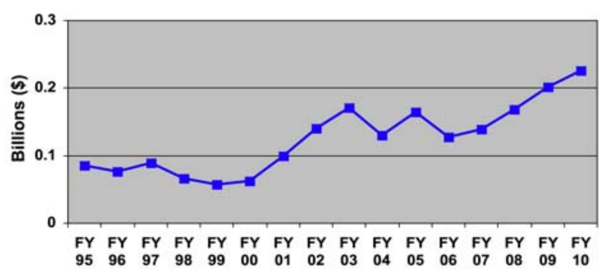

Figure 4: DARPA's Basic Research funding (current dollars).

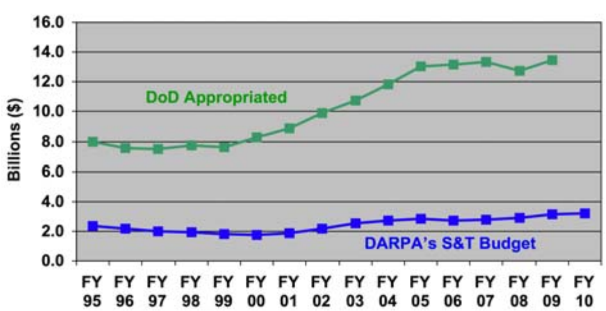

Figure 5: Total S&T funding in DoD and DARPA (current dollars).

Basic research is primarily supported by the Service S&T organizations, such as the Office of Naval Research, and other federal agencies like the National Science Foundation, the National Institutes of Health, and the Department of Energy. Basic research creates new knowledge and capability, whereas DARPA also creates new capabilities for national security by accelerating that knowledge and capacity into use.

DARPA uses its 6.1 funding to "get a seat at the table" with basic research performers so that DARPA can understand what is going on at the forefront of science and can mine that research for new Defense capabilities.

Figure 4 shows DARPA's funding of Far side basic research since FY 1995.

Shaping DARPA's Strategy

Basic Challenge and Focus: A basic challenge for any military research organization is matching military problems with technological opportunities, including the new operational concepts those technologies make possible. Parts of this challenge are extremely difficult because: (1) some military problems have no easy or obvious technical solutions; and (2) some emerging technologies may have far-reaching military consequences that are still unclear. DARPA focuses its investments on this "DARPA-hard" niche – a set of technical challenges that, if solved, will be of enormous benefit to U.S. national security, even if the risk of technical failure is high. Other factors also shape DARPA's investments:

- DARPA emphasizes research the Services are unlikely to support because it is risky, does not fit their specific role or missions, or challenges existing systems or operational concepts;
- DARPA focuses on capabilities military commanders might want in the future, not what they know they want today;
- DARPA insists that all programs start with good ideas and good people to pursue them; without both of these things, DARPA will not start a program.

Notable Features: DARPA's decision-making process is informal, flexible, and yet highly effective because it focuses on making decisions on specific technical proposals based on the factors discussed above.

There are two reasons for this. DARPA is a small, flat organization rich in military technological expertise. There is just one porous management layer (the Office Directors) between the program managers and the Director. With about 120 technical personnel, it is easy to make decisions. This management style is essential to keeping DARPA entrepreneurial, flexible and bold. DARPA's management philosophy is to pursue fast, flexible, and informal cycles of "think, propose, discuss, decide, and revise." This approach may not be possible for most larger government agencies, but it has worked well for DARPA.

The Basic Process: DARPA uses a top-down process to define problems and a bottoms-up process to find ideas, involving the staff at all levels. DARPA's management and program managers identify "DARPA-hard" problems by talking to many different people and groups. (See "DARPA's Outreach" on p. 6) This process includes:

- Specific assignments from the Secretary of Defense, Under Secretary for Acquisition, Technology and Logistics, or Director, Defense Research and Engineering;
- Requests for help from the Service Secretaries and Chiefs, Joint Staff, and Unified Combatant Commanders;
- Discussions with senior military leaders on "What are the things that keep you awake at night?";
- Research into recent military operations to find situations where U.S. forces have limited capabilities and few good ideas;
- Discussions with Defense Agencies such as the Defense Threat Reduction Agency, the National Geospatial-Intelligence Agency, the Defense Information Systems Agency, and the Defense Logistics Agency;
- Discussions with intelligence community agencies such as the Central Intelligence Agency and the National Security Agency; and
- Discussions with other government agencies or outside organizations such as the National Science Foundation and the National Academy of Sciences.
- Visits to Service exercises or experiments.

During DARPA's program reviews, which occur throughout the year, DARPA's upper management looks for new ideas from program managers (or new program managers with ideas) for solving these problems. At the same time, management allocates funds for exploring highly speculative technology that has far-reaching military consequences.

Program managers get ideas from many different sources, such as:

- Their own technical communities;
- Suggestions from DoD advisory groups, such as the Defense Science Board and Service science boards;
- Suggestions from DARPA-sponsored technical groups, including the Information Science and Technology Study Group and the Defense Science Research Council;
- Suggestions from industry or academia, often in response to published Broad Agency Announcements or open industry meetings such as DARPATech;
- Surveys of international technology;
- Breakthroughs in DARPA or other research programs; and,
- Small studies and projects used to flesh out ideas, often referred to as "seedlings."

DARPA's strategy and budget is reviewed thoroughly by the Under Secretary for Acquisition, Technology and Logistics and Director, Defense Research and Engineering.

Vetting a Program: During reviews of both proposed and on-going programs, DARPA's assessment is often guided by a series of questions. These seemingly simple queries help reveal if a program is right for DARPA:

- What is the program trying to do?
- How is it done now and what are the limitations?
- What is truly novel in the approach that will remove those limitations and improve performance? By how much?
- If successful, what difference will it make?
- What are the interim technical milestones required to prove the hypothesis?
- What is the transition strategy?
- How much will it cost?
- Are the programmatic details clear?

Figure 5 shows DARPA's total S&T funding (Budget Activities 6.1, 6.2, and 6.3) in comparison to DoD's overall S&T budget. DARPA typically accounts for about 25 percent of DoD's S&T budget. This is in line with the common industry practice of devoting about 75 percent of R&D funding to product improvement but allocating 25 percent for new ideas, products, and markets.

Note that DARPA's funding for Basic Research (Budget Activity 6.1) increased by a factor of two since 2000, during which time the overall DARPA funding increased only by a factor of 1.5. Hence, DARPA's funding of "6.1" Basic Research activities not only increased since 2000, but increased proportionally at a faster rate than DARPA's overall budget.

By mining the Far side and bridging the gap between what *might be* done and what *is* done, DARPA attempts to prevent technological surprise for the United States, while creating technological surprise for our adversaries.

2.3. Shaping Programs

DARPA's senior management meets frequently with civilian and military leaders throughout DoD to understand operational challenges, discuss with them what DARPA is working on that might help, and ask them, "What are the operational challenges that cause you the deepest concern? What are the problems that keep you up at night?" (See inset, "DARPA's Outreach.") These discussions, coupled with constantly monitoring the Far side for potential solutions, keep DARPA's strategy matched with DoD's hardest technical problems and greatest technical opportunities.

DARPA's Outreach

Among the senior officials who have been briefed on DARPA's strategy over the past two years are:

- The Vice President
- Deputy Secretary of Defense
- Secretary of the Army
- Secretary of the Navy
- Under Secretary of Defense for Intelligence
- Chief of Staff, Air Force
- Commandant of the Marine Corps
- Chief of Naval Operations
- Commander, U.S. Southern Command
- Commander, U.S. Special Operations Command
- Commander, U.S. Strategic Command
- Under Secretary of the Air Force
- Assistant Secretary of Defense for Special Operations and Low Intensity Conflict
- General Counsel of the Department of Defense
- Director, Operational Test and Evaluation
- Vice Chief of Staff, Army
- Vice Chief of Staff, Air Force
- Chairman, Joint Requirements Oversight Council
- Commander, Army Materiel Command
- Commander, Air Mobility Command
- Commander, Army Training and Doctrine Command
- Commander, Air Combat Command
- Deputy Under Secretary of Defense for Acquisition and Logistics
- Deputy Under Secretary of Defense for Intelligence, Joint and Coalition Warfighter Support
- Director, Defense Intelligence Agency
- Director, National Geospatial-Intelligence Agency
- Deputy Commander, U.S. Special Operations Command
- Director, Joint Improvised Explosive Device Defeat Organization
- Military Deputy, Office of the Assistant Secretary of the Air Force for Acquisition
- Surgeon General of the Air Force
- Commander, Marine Corps Combat Development Command
- Director, National Security Agency
- Director, Naval Intelligence (N2)
- Commander, Naval Air Systems Command
- Commander, Naval Sea Systems Command
- Director, Command, Control, Communications, and Computer Systems (J6), Joint Chiefs of Staff
- Deputy Chief, Naval Operations for Communication Networks (N6)
- Deputy Chief, Naval Operations for Integration of Capabilities and Resources (N8)
- Commander, Submarine Force
- Deputy Surgeon General of the Navy
- Deputy Surgeon General of the Air Force
- Commanding General, Army Medical Research and Materiel Command
- Commander, Army Research Development and Engineering Command
- Director, Plans, Programs, Requirements and Assessments, Air Education and Training Command
- Director, Submarine Warfare Division (N87)
- PEO for Unmanned Aviation and Strike Weapons (N88)
- Director, Defense Procurement, Acquisition Policy and Strategic Sourcing
- Deputy Director, National Security Agency

To keep current with the real-life facts-on-the-ground, DARPA's senior leadership and technical program managers visit military bases, commands, training centers, and other facilities to talk with warfighters and get a sense of their problems (Figure 6).

- **US Marine Corps Warfighting Lab, Quantico, VA**
- **29 Palms**
- **Iraq, Afghanistan**
- **US Navy Carrier Visits, CA**
- **US Air Force Air Armaments Center, FL**
- **US Special Operations Command, Tampa, FL**
- **US Air Force Special Operations Command, Hurlburt Field, FL**
- **US Army Intelligence and Signals Command, VA**
- **US Air Force Test Wing, Edwards AFB, CA**
- **Naval Special Warfare Command, San Diego, CA**
- **Naval Surface Forces Command, San Diego, CA**
- **III Corps and Ft. Hood, TX**
- **Biannual Air Force Space Command Days**
- **Nellis Air Force Base, NV**
- **Quarterly Meetings with Chief of Staff of the Air Force**
- **Quarterly Meetings with Service Secretaries**
- **Edwards Air Force Base, CA**
- **National Training Center, Fort Irwin, CA**
- **Mayport/Keywest, FL – SOUTHCOM, NAVSOUTH/JIATF-S**

Figure 6: DARPA's senior leadership and technical program managers have visited numerous military bases, commands, training centers, and other Defense facilities.

2.4. Assessing Program Progress

DARPA has a rigorous and structured process for evaluating the progress of its programs. At the start of every program, DARPA spends considerable effort defining a series of "Go/No-Go" milestones that will be the linchpins for this evaluation. Go/No-Go's are key technical accomplishments that must be achieved before it makes sense to start the next phase of the program. Conversely, they can be thought of as those things that if not achieved could cause the entire program to fail.

DARPA only funds its programs up to the next Go/No-Go milestone, meaning that the program must pass a Go/No-Go review before it receives more funds. This keeps the program managers and contractors highly focused on reaching their Go/No-Go goals.

A Go/No-Go review can have a number of different outcomes. A program (or project within a program) may pass and be funded for the next phase. Or, it may fail and be canceled. Or, not uncommonly, it may be held back from the next phase while using some additional funds to achieve the current Go/No-Go goal more fully. Or, the overall goals of the program may be modified to reflect what has been learned so far in order to proceed in a realistic and productive manner.

The point of the Go/No-Go review is to force a careful technical assessment of a program's progress and to avoid continuing to fund a program simply because of momentum or the hope that some key technical requirement will eventually be achieved.

2.5. Major Accomplishments

For nearly five decades, DARPA's management methodology has been very successful at "bridging the gap."[5] Figure 7 shows icons that illustrate some of DARPA's preeminent accomplishments since the early 1960s.[6]

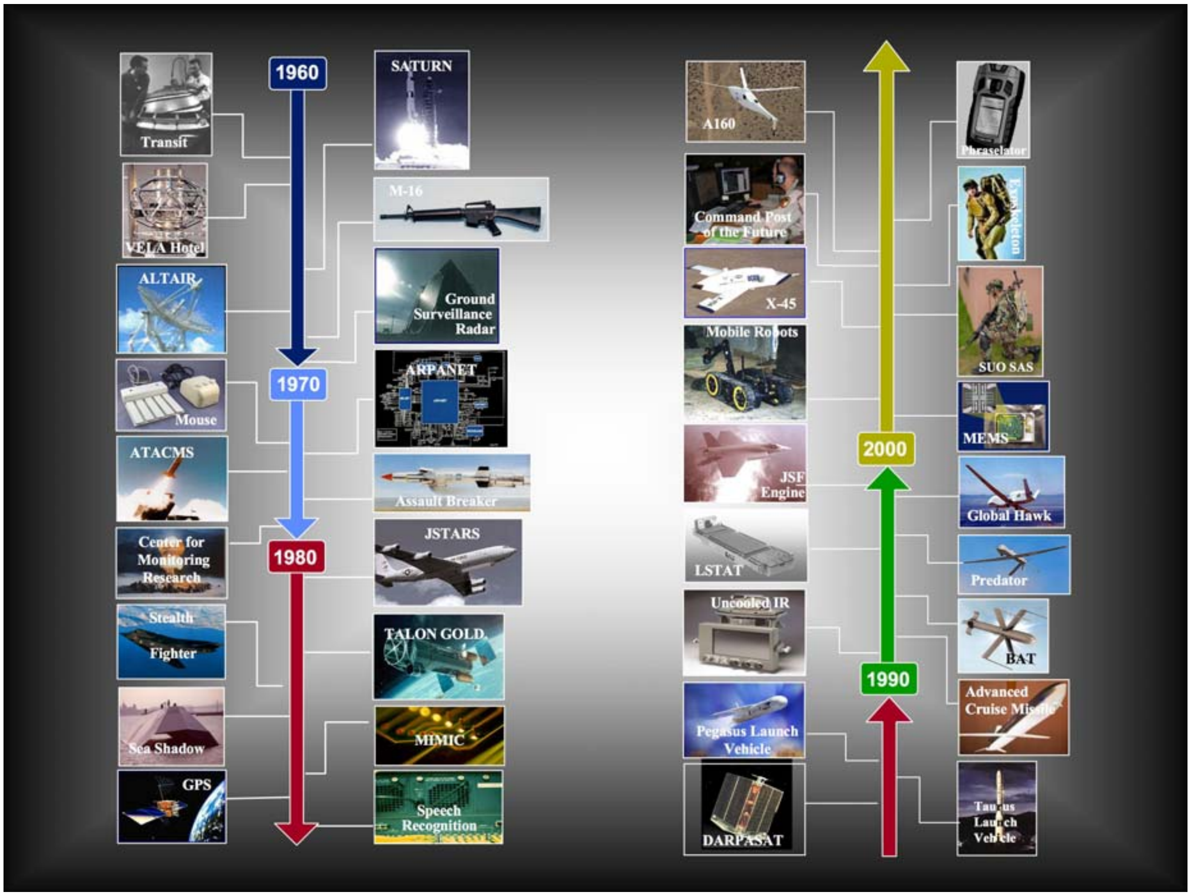

Figure 7: Key DARPA accomplishments spanning more than five decades.

DARPA was borne of the space age. The launch of Sputnik in 1957 also launched DARPA, so all the Agency's initial projects were space-related.

The Agency nearly ceased to exist when DARPA's space programs were transferred over to the National Aeronautics and Space Administration and the National Reconnaissance Office. But a new mission emerged to counter a new threat: intercontinental ballistic missiles. From approximately 1960 to 1970, DARPA was a driving force behind the United States' technology advancements in ballistic missile defense. In 1968, the Army Ballistic Missile Defense Agency was created, and the ballistic missile defense mission was transferred from DARPA.

DARPA began developing the technologies for stealthy aircraft in the early 1970s under the HAVE BLUE program, which led to prototype demonstrations in 1977 of the Air Force's F-117

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5 In 2003, the Institute for Defense Analysis released its reports documenting the major contributions DARPA system projects made to the revolution in military affairs; these reports can be found at www.darpa.mil/Docs/P-3698_Vol_1_final.pdf and www.darpa.mil/Docs/P3698_DARPA_VolII.pdf.

6 A detailed graphic history of DARPA's 50 years of "Bridging the Gap" is available at www.darpa.mil/Docs/50yearstimeline1_200807180942211.pdf.

tactical fighter that proved so successful in Operation Desert Storm. After the successes of the DARPA HAVE BLUE Stealth Fighter program, DARPA launched the TACIT BLUE technology demonstration, contributing directly to the development of the B-2 bomber deployed by the Air Force.

The Global Hawk and Predator unmanned aerial vehicles (UAVs) have been prominent in Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom. DARPA started on the concept of a high-altitude, long-range, extended-loiter, unmanned system in the 1970s with the TEAL RAIN program. After a number of significant technical breakthroughs, the Global Hawk high-altitude endurance UAV transitioned from DARPA to the Air Force in 1998. The Tier 2 Predator medium-altitude endurance UAV evolved directly from DARPA's AMBER and Gnat 750-45 designs and was operationally deployed in the mid-1990s.

The most well-known of all DARPA technologies is the Internet, which began in the 1960s-1970s with the development of the ARPANet and its associated TCP/IP network protocol architecture. DARPA's development of packet switching is the fundamental element of both public and private networks spanning DoD, the Federal Government, U.S. industry, and the world.

DARPA's developments in distributed command and control, tied together by robust, secure, self-forming networks, have led to the Command Post of the Future (CPOF) being used today by the Army in Iraq. CPOF allows command and control centers to be wherever the commanders are, without regard to a fixed geographic location.

A crucial characteristic about several of these accomplishments, which holds true for many DARPA programs, is that it took a long time from an idea's conception to its use by the U.S. military. DARPA has shown itself very willing to repeatedly tackle hard technical problems, even in the face of previous failure, if the technology offers revolutionary new capabilities for national security. Patience and persistence are required for those who pursue high-risk technology, but they are often rewarded with extremely large payoffs.

2.6. Future Icons

It is often said that past results do not necessarily indicate future success. Nevertheless, the following is a "short list" of ongoing DARPA research that promises major military benefits. In a few years these "Future Icons" may well take their places in the gallery of key DARPA accomplishments illustrated in Figure 7. Each of these will be further discussed later in the corresponding sections identified in each description.

- **Accelerated Development and Production of Therapeutics**: rapidly and inexpensively manufacture millions of doses of life saving drugs or vaccines in weeks, instead of the years required to ramp up today's manufacturing practices (Section 3.8).
- **Air Vehicles**: unmanned air vehicles that quickly arrive at their mission station and can loiter there for very long periods (Section 3.4).
- **Alternative Energy**: technologies to help reduce the military's reliance on petroleum (Section 3.9.4).
- **Blue Laser for Submarine Laser Communications:** provide for timely, large area submarine communications at speed and depth, which no other future or existing system, or combinations of systems, can do (Section 3.1).

- **High Energy Liquid Laser Area Defense System**: novel, compact, high power lasers making practical small-size and low-weight speed-of-light weapons for tactical mobile air- and ground-vehicles (Section 3.9.9).
- **High Productivity Computing Systems**: supercomputers are fundamental to a variety of military operations, from weather forecasting to cryptography to the design of new weapons; DARPA is working to maintain our global lead in this technology (Section 3.7).
- **Machine Learning:** the world's first integrated cognitive assistant that learns on the job and adapts on its own, and new learning technologies that: observe users' actions and learn their activities, roles, topics, and preferences; respond to users' advice; anticipate their information needs; and, learn new tasks (Section 3.7).
- **National Cyber Range**: The National Cyber Range will provide an environment for realistic, qualitative and quantitative assessment of potentially revolutionary cyber research and development technologies (Section 3.1).
- **Persistent Surveillance Sensors**: determine, track, and neutralize elusive threats, such as improvised explosive device factories (Section 3.2).
- **Networks**: self-forming, robust, self-defending networks at the strategic and tactical level are the key to network-centric warfare; these networks will use spectrum far more efficiently and resist disruption if the GPS time signal is unavailable (Section 3.1).
- **Neuroscience:** using new insights from neuroscience to find images of interest amongst clutter; improve individual training; identify the origins of traumatic brain injury; and create prosthetics that can be perceived and controlled by the brain just like a natural limb (Section 3.8).
- **Non-Silicon Electronics:** alternatives to traditional silicon chips are providing key military systems advantages in terms of operating speed, handling enormous power levels or, on the other end of the spectrum, dramatically reducing power consumption (Section 3.9.5).
- **Quantum Information Science**: exploiting quantum phenomena in the fields of computing, cryptography, and communications, with the promise of opening new frontiers in each area (Section 3.9.1).
- **Real-Time Accurate Language Translation**: real-time machine language translation of structured and unstructured text and speech with near-expert human translation accuracy (Section 3.7).
- **Space**: maintain the U.S. military's strategic defense advantage in space by continuing to develop advanced space capabilities for global military operations (Section 3.6).
- **Submarines**: reduce size and cost, while maintaining existing capabilities (Section 3.4).
- **Trustworthy Integrated Circuits:** Techniques to ensure that integrated circuits upon which critical DoD systems depend will operate exactly as designed and not contain possible malicious circuitry or programming (Section 3.1).
- **Warfighter Effectiveness and Survival**: helping to keep U.S. warfighters safe and effective with advanced armor, improved training, and technologies to maintain their health and treat their injuries in the field (Sections 3.3 and 3.8).

2.7. Transitioning Technologies

Transitioning technology – getting technology from research and into use – is a contact sport. It is done by personal contacts between people.

Many different types of organizations may need to be involved, i.e., S&T organizations like DARPA, the acquisition community, the warfighting/requirements community, and the firms that actually produce the product. This requires personal contact between the people developing the technology and those destined to receive it.

The very nature of a technology strongly shapes how it transitions. For example, a component technology like a new material or microchip is likely to get to the warfighter when a prime contractor incorporates it into a system, without a Service acquisition program necessarily having decided on it *per se*. This means the key component decisions are made by industry – prime contractors and subcontractors.

On the other hand, a large system development program such as Global Hawk requires the warfighting community to establish a formal requirement for the system, thereby charging the acquisition community with actually purchasing it. New systems simply do not diffuse their way into military use like a new material might.

The transition challenge is exacerbated for DARPA because its focus is on high-risk, revolutionary technologies and systems, which may have no clear home in a Service, are Joint, or threaten to displace current equipment or doctrine. Such factors tend to create resistance, or at least barriers to the use and adoption of a radically new technology.

Figure 8 is an illustration of DARPA's strategy to transition technology to the warfighter.

Figure 8: DARPA transition methods.

The first bar illustrates the majority of DARPA's transition activities. DARPA invests about 98 percent of its funds at organizations outside DARPA, primarily at universities and in industry. Over time, this investment leads to new capabilities in industry and steadily reduces the risks of the underlying technology. At some point, a company becomes sufficiently confident of the capability, value and technical maturity of a new technology for a predictable cost and schedule. It will then be willing to propose the technology to DoD users or acquisition programs. DARPA's investment reduces the risk of a technology to the point where firms themselves are willing to make it, use it, or otherwise bid it back to the rest of DoD.

Companies generally will not propose a new technology to a Service if they are not confident the Service will accept it. The second bar in Figure 8 shows how DARPA removes this impediment. To build potential Service customers for DARPA technology – someone to whom these companies can bid with confidence – DARPA deliberately executes most of its funding through the Services. That is, a Service organization serves as DARPA's agent, signing the contracts with the research performers and monitoring the day-to-day technical work. This investment

Working with USSOCOM

Over the last several years, DARPA has forged a close working relationship with USSOCOM based on the good strategic fit and synergy between the two organizations. USSOCOM has sophisticated operators who face difficult problems that might be solved with advanced technology and who can use experimental equipment in small quantities. DARPA is well-placed to supply that technology and is interested in getting feedback on its work. Both organizations are small and agile. In the short term, this relationship offers DARPA a good opportunity to test emerging technical solutions against difficult problems. In the longer term, it helps USSOCOM shape its view of what is and will be technically possible, and it influences what technology DARPA pursues.

To strengthen the systematic transition of its technology to USSOCOM, DARPA has a representative detached to the Command. The DARPA representative is posted at USSOCOM and works to bring USSOCOM and DARPA together across a range of programs and challenges. This can vary from co-investing in a program, to USSOCOM testing DARPA technology, to getting USSOCOM's inputs to strengthen DARPA goals and prototypes. USSOCOM is a partner or participant in numerous DARPA programs and has endorsed or influenced many others.

Among the recent fruits of this relationship are advanced runway lighting and flashlights, water purification pens, hand-held radars that look through walls, unmanned aerial vehicles, sensor devices, foliage penetration, translation systems, revolutionary modeling and simulation, and communication technology.

creates a cadre of people inside a Service who are familiar with a DARPA technology, who can vouch for it, and who can shepherd it into a Service acquisition program. Once the company is confident it can build a technology and a Service is willing to accept it, the technology transitions and DARPA's role in the development is, typically, forgotten.

DARPA occasionally builds prototypes of a large, integrated system such as Global Hawk. Such programs reduce the risks in a new system to the point where the warfighting community can be confident it will get a new and cost-effective capability. However, without proper planning such programs can run into a two-year funding gap between the time the Service is convinced it wants the system and when the DoD financial system can effectively respond. To prevent these and other problems, DARPA tries to ensure transition of prototypes by negotiating a memorandum of agreement (MOA) with the Service adopting the system. In general, for its Advanced Technology Development (i.e., "6.3") programs, DARPA requires that an MOA or a transition strategy be negotiated with a Service at some predetermined point during the program's development in order to proceed to its later stages.

DARPA has several initiatives to help transition technology:

- DARPA's *Service Chiefs Program* is a joint program between DARPA's Director and the Chief of Staff of each Service, and the Director of the National Geospatial-Intelligence Agency (NGA). Under the program, each Service and the NGA detail young, talented officers to DARPA as interns on a three-month basis to give them an in-depth look at DARPA's programs and way of doing business. The interns also help DARPA's program managers better understand existing military capabilities and combat operations. During the last seven years, over 200 officers from all the Services have participated in the program, which has proven valuable in transitioning DARPA technology to the Services. However, the real value of the program is long-term. As these young officers progress through their careers, being exposed to DARPA at an early stage should make them more open to new technology and hence be even more valuable to U.S. national security.

- *Operational Liaisons* from each military Service, the National Geospatial-Intelligence Agency, the Defense Information Systems Agency, and the National Security Agency are assigned to the Director's Office at DARPA.

Under the leadership of the DARPA Director's Special Assistant for Technology Transition, this team's everyday job is to maintain DARPA's connection to real-life problems, while at the same time helping transition DARPA technology to the Services. DARPA's Operational Liaisons, through their close relationships with their respective Service or Agency, ensure that DARPA program managers and warfighters are brought together so the managers can better understand the warfighter's needs, and the warfighters can better understand upcoming technological opportunities. This individual brokering of connections is consistent with DARPA's general philosophy that technology transition is a contact sport. DARPA's Operational Liaisons are usually very senior both in rank and experience, come with a great set of contacts, and help reinforce the day-to-day linkages between DARPA's research programs and the needs and opportunities of DoD.

DARPA has also detailed a representative to the U.S. Special Operations Command (USSOCOM) in Tampa, Florida, to maximize the flow of new technology to our Special Forces with a minimum of bureaucracy, an approach that has worked extremely well.

Please see Section 5 for contact information for these individuals.

3. Current Strategic Thrusts

Strategy is the evolving approach to pursuing a central mission through changing circumstances. Consequently, over time, DARPA changes much of what it is doing in response to the different national security threats and technological opportunities facing the United States.

While much of DARPA's work can take many years to reach fruition, in times of active conflict – such as today – DARPA's agility allows it to focus some of its resources on quickly meeting the needs of U.S. forces in combat. This can involve accelerating projects, harvesting the results of previous work which were never fully implemented, or pursuing new high-risk, high-reward ideas that can be quickly tested.

DARPA does not allocate funding *a priori* to each strategic thrust; it would be difficult, if not impossible, to do that wisely. Instead, the thrusts focus the agency's attention on a set of problems or challenges, but DARPA funds specific ideas and opportunities. The amount of funds in a thrust is the sum of the funds in the ideas.

An important element of DARPA's work is to "red team" how an adversary would react. That is, how would an adversary respond to a new technological development by the United States? An expensive new technology that is easy and inexpensive to negate may not be that useful, whereas one that that is hard to counter may be extremely valuable. DARPA conducts its programs mindful that "the enemy gets a vote."

DARPA currently emphasizes research in nine strategic thrusts:

- Robust, Secure, Self-Forming Networks
- Detection, Precision ID, Tracking, and Destruction of Elusive Targets
- Urban Area Operations
- Advanced Manned and Unmanned Systems
- Detection, Characterization, and Assessment of Underground Structures
- Space
- Increasing the Tooth to Tail Ratio
- Bio-Revolution
- Core Technologies

3.1. Robust, Secure, Self-Forming Networks

The DoD is in the middle of a transformation to what is often termed "Network-Centric Operations." The promise of network-centric operations is to turn information superiority into combat power so that the U.S. and its allies have better information and can plan and conduct operations far more quickly and effectively than any adversary.

At the core of this concept are robust, secure, and self-forming networks. These networks must be at least as reliable, available, secure and survivable as the weapons and forces they connect. They must distribute huge amounts of data quickly and precisely across a battlefield, a theater, or the globe, delivering the right information at the right place at the right time. DoD's networks are becoming as important to its military success as its weapons platforms.

But in order for these networks to realize their full military potential, they must form, manage, defend, and heal themselves so they always function at the enormously high speeds that provide their advantages. This means that *people* can no longer be central to establishing, managing, and administering them.

Key challenges and opportunities in this area for DoD are shown in Figure 9. Tactical networks must locally link effects to targets and be agile, adaptive and versatile. Strategic and operational networks must globally link air, ground, and naval forces for operational maneuver and strategic

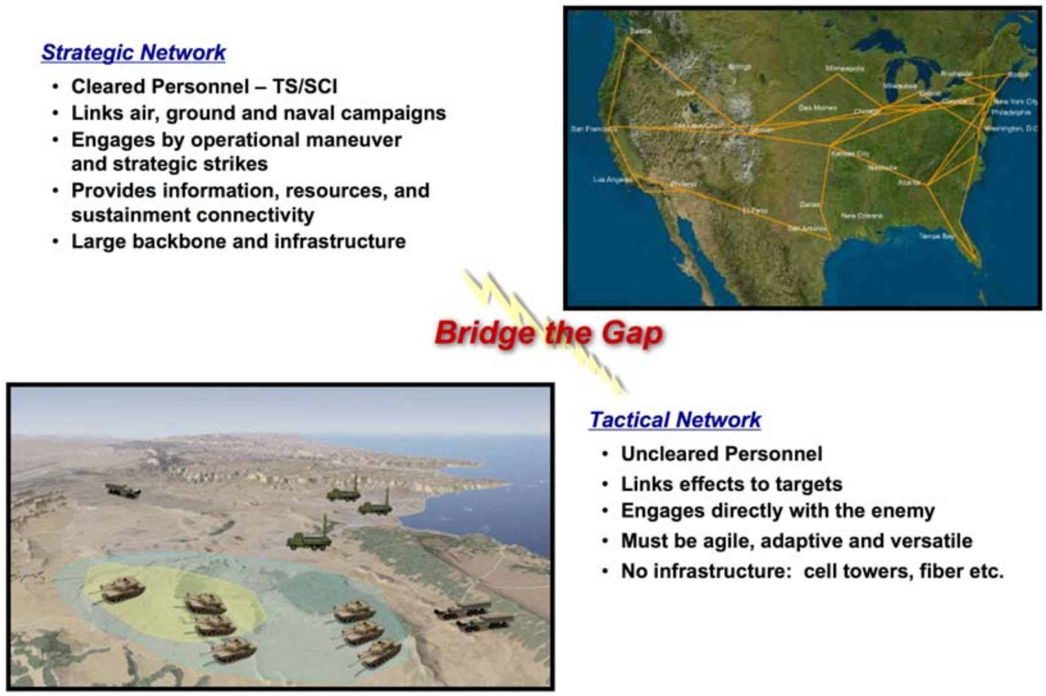

Figure 9: Bridging the Network-Centric Operations gap between strategic/operational and tactical levels of deployment and warfare.

strike, and enable knowledge, understanding, and supply throughout the force. And there now exists the opportunity to bridge the gap between these two families of networks and allow the strategic and tactical echelons to rapidly and effectively share information and insight.

DARPA is developing technologies for wireless tactical net-centric warfare that will enable reliable, mobile, secure, self-forming, ad hoc networking among the various echelons while using available spectrum very efficiently.

A seminal effort was the Small Unit Operations Situational Awareness System (SUO SAS) program, completed several years ago. SUO SAS created the first self-forming, self-healing communication system for dismounted forces operating in difficult environments, such as cities and forests. The technology was adopted by the Army.

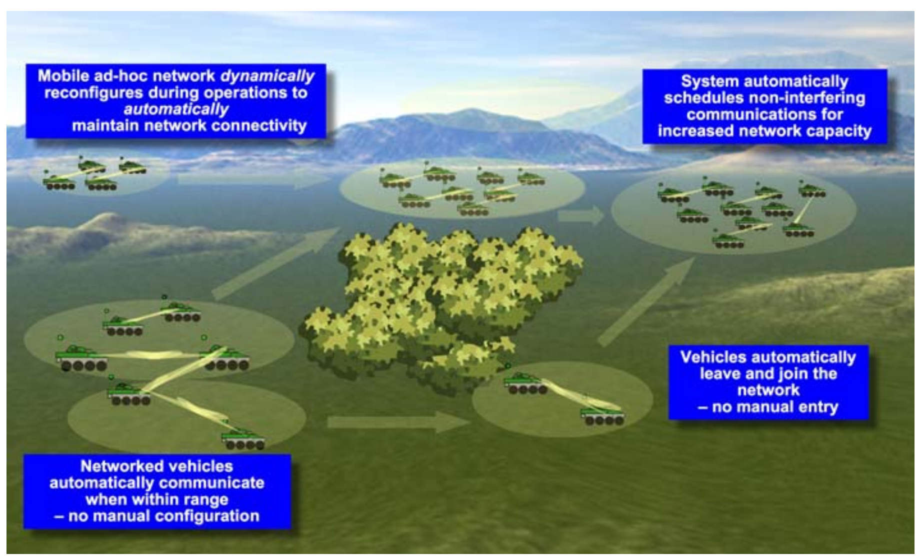

Figure 10: DARPA's Network Centric Radio System – a dual-rate, mobile ad hoc network for the maneuver force.

The next logical step was to connect different tactical ground, airborne and satellite communications platforms and terminals together. The Network Centric Radio System (NCRS) program (Figure 10) has developed a mobile, self-healing ad hoc network gateway approach that provides total radio/network interoperability among these platforms on-the-move in any terrain – including the urban environment.

Limited radio interoperability has plagued the Department of the Defense for decades. NCRS builds interoperability into the network itself, rather than having to build it into each radio, so any radio can now talk to any other. Today, previously incompatible tactical radios – military legacy, coalition, first responder and future radios – can talk seamlessly among themselves and to more modern systems, including both military and commercial satellite systems.

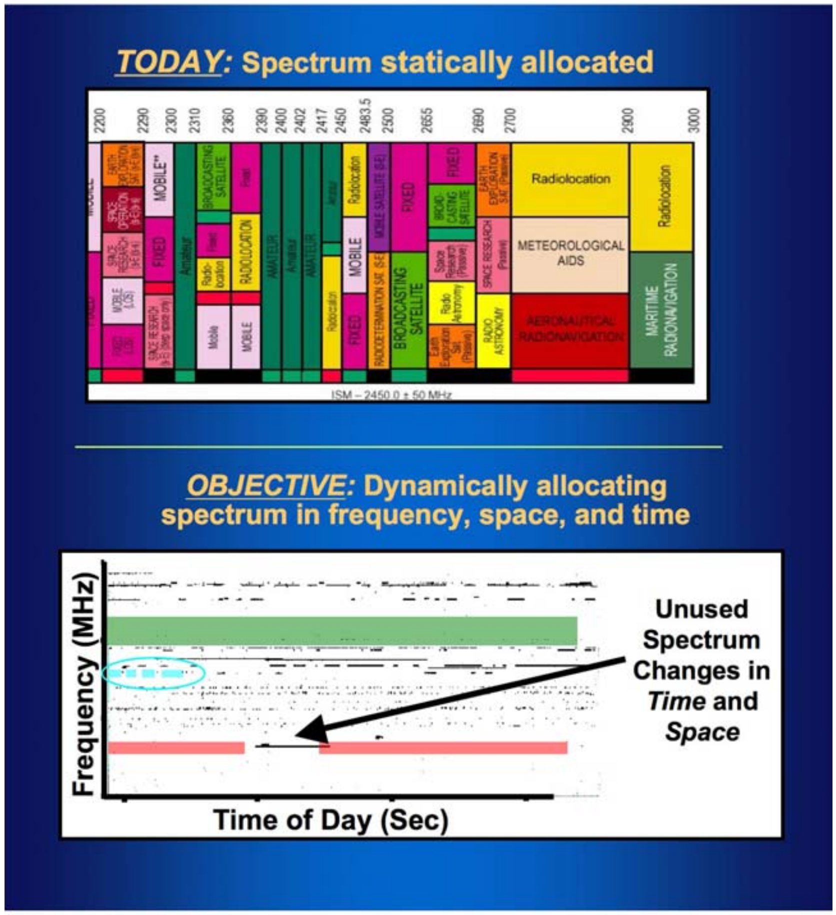

Figure 11: XG Communications technology and system concepts for dynamic spectrum access.

Frequency spectrum is scarce and valuable. Most of the radio frequency spectrum is already allocated to users who may or may not be using it at a given time and place. DARPA's neXt Generation (XG) Communications technology (Figure 11) will effectively make up to ten times more spectrum available by taking advantage of spectrum that has been assigned but is not being used at a particular point in time. XG technology senses the actual spectrum being used and then dynamically uses the spectrum that is not busy at that particular place and time. XG resists jamming and does not interfere with other users.

DARPA also has been developing autonomous network communications for the cluttered environment of cities. Urban clutter usually creates multiple signals from diverse reflections of the initial signal (multi-path), and the result is weak and/or fading voice/data communications. Turning this problem into an opportunity, the Mobile Networked Multiple-Input/Multiple-Output (MNM) program is actually exploiting multipath phenomena to improve communications between vehicles moving in cities without using a fixed communications infrastructure.

Building on XG, MNM, and adaptive networking technologies, the Wireless Network after Next (WNaN) program is developing technology and architecture to enable an affordable and rapidly deployable communication system for the "tactical edge." The low-cost, highly capable radio developed by WNaN will provide the military with the capability to communicate with every warfighter and every device at all operational levels. WNaN networking technology will exploit high-volume, commercial components and manufacturing processes so that DoD can affordably and continuously evolve the capability over time.

Besides tactical networking, DARPA is bridging strategic and tactical operations with high-speed, high-capacity communications networks. The Department's strategic, high-speed fiber optic network, called the Global Information Grid (GIG), has an integrated network whose data rate is hundreds to thousands of megabits per second. To reach the theater's deployed elements, data on the GIG must be converted into a wireless format for reliable transmission to the various elements and echelons within the theater. This data rate mismatch creates problems in the timely delivery of information to the warfighter.

In response to this challenge, DARPA has been working on robust network management to combine the high data-rate capability of laser communications with the high reliability of radio frequency communications and obtain the benefits of both.

DARPA's Optical RF[7] Communications Adjunct (ORCA) program (Figure 12) will design, build, and demonstrate a prototype tactical network connecting ground-based and airborne elements. ORCA's goal is to create a high data rate backbone network, via several airborne assets that nominally fly at 25,000 feet and up to 200 kilometers apart, which provides GIG services to ground elements up 50 kilometers away from any one node.

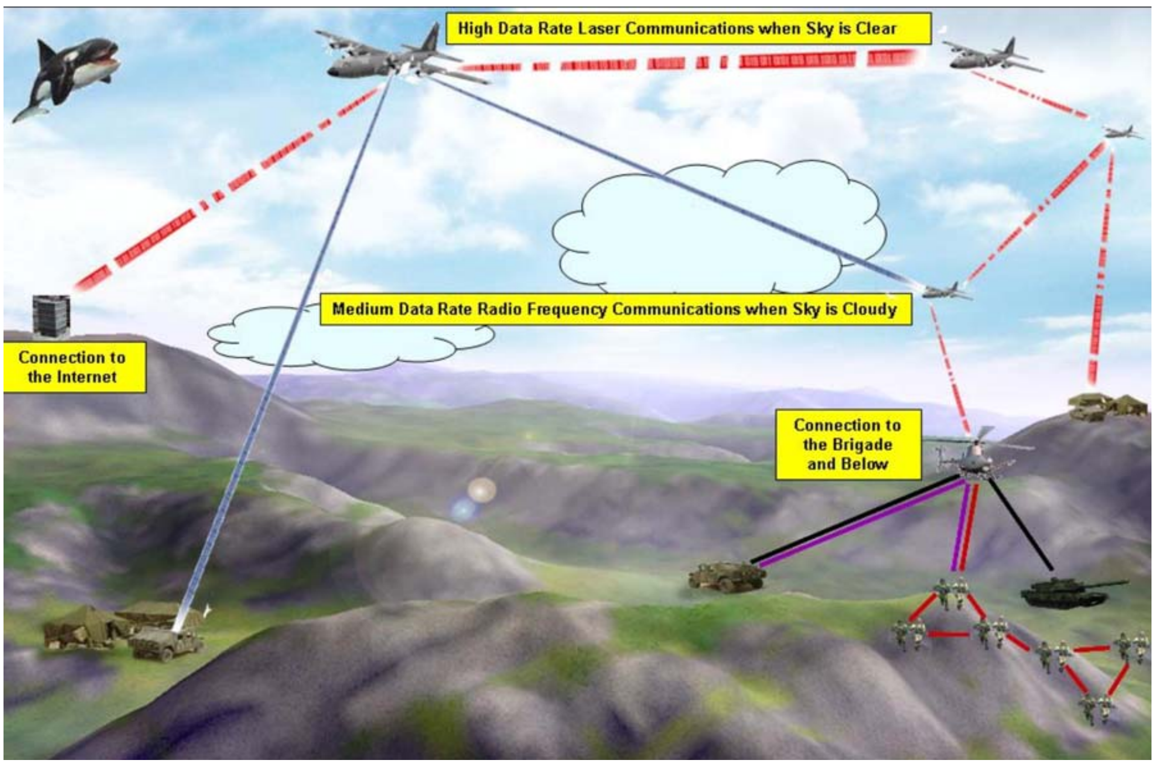

Figure 12: The Optical RF Communications Adjunct (ORCA) program will design, build, and demonstrate a prototype tactical network connecting ground-based and airborne elements

DARPA also is working to bridge strategic and tactical maritime operations with a revolutionary new capability for submarine communications. The Navy has long sought a method for two-way communications with submarines traveling at speed and depth. Currently deployed technology offers only one-way communications to deeply submerged boats at low data rates using towed antennas that significantly constrain maneuvers. These submarines cannot transmit information back without surfacing and, perhaps, revealing their position. Laser-based communications with

[7] Radio Frequency

submarines offers the promise of two-way communications at speed and depth without the current submarine maneuver restrictions. Unfortunately, that promise has been elusive until now. Practical laser-based systems for deep depths were unavailable because lasers operating at the right color with enough power efficiency to be used in satellites did not exist.

DARPA is striving towards a blue laser efficient enough to make submarine laser communications at depth and speed a near-term reality. A recently demonstrated laser will be matched with a special optical filter to form the core of a communications system with a signal-to-noise ratio thousands of times better than other proposed laser systems. If DARPA can demonstrate such a system under realistic conditions, it would dramatically change how submarines can communicate and operate, thereby greatly enhancing mission effectiveness, for example, in anti-submarine warfare.

DARPA is seeking to improve DoD's global strategic network capability by developing the extremely high bandwidth, high-speed, pervasive networks needed for global communications and data exchange. The Next Generation Core Optical Networks (CORONET) program will leverage DARPA's photonics and secure networking programs to revolutionize the operation, performance, security, and survivability of DoD strategic networks (Figure 13). The program will develop the architecture, protocols, and control and management software for highly dynamic, multi-terabit global core optical networks with greatly enhanced performance, security and survivability to enable ultra-fast service set-up and tear-down, as well as very fast recovery from multiple network failures.

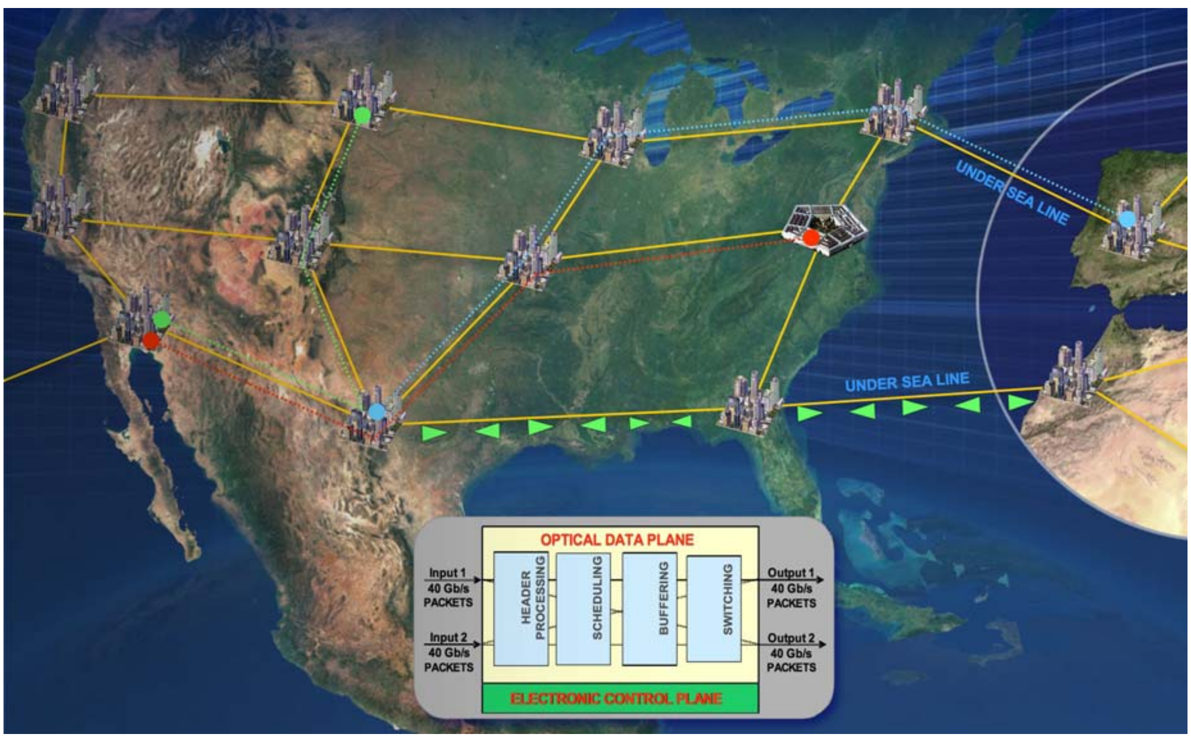

Figure 13: The goal of the Next Generation Core Optical Networks (CORONET) program is to increase optical network throughput with reduced latency and operational cost.

Our tactical and strategic networks must be fast and robust, but they must be protected. DARPA is developing technologies to make computers and their networks not only secure, but also disruption-tolerant and, when attacked, self-reconstituting.

Networks rely on a widely available timing signal, or common clock, to sequence the movement of voice and data traffic and to enable encryption. The timing signal is often provided by the Global Positioning System (GPS) or broadcast via other radio signals. We should expect adversaries to attack our networks by blocking these timing signals. DARPA has been developing a miniature atomic clock – measuring approximately one cubic centimeter – to supply the timing signal should the external signal be lost. The Chip-Scale Atomic Clock (CSAC) (Figure 14) will allow a network node, such as a warfighter using a Single Channel Ground and Airborne Radio System (SINCGARS), to maintain synchronous operation with the network for several days after loss of the GPS signal.

Figure 14: Chip-Scale Atomic Clock: ultra-miniaturized, low-power, atomic time and frequency reference units.

As the U.S. military adopts network-centric warfare, adversaries are likely to develop and employ malicious code to impede our ability to fight efficiently and effectively. The ever-growing sophistication of this threat has surpassed the ability of normal commercial markets to provide solutions for DoD. For example, computer worms that have never been seen before ("zero-day worms") pose a specific threat to military networks because they exploit thousands of computers using previously unknown network vulnerabilities in seconds.

The Dynamic Quarantine of Computer-Based Worm Attacks program has been developing dynamic quarantine defenses for U.S. military networks against large-scale malicious code attacks, such as computer-based worms, by creating an integrated system that automatically detects and responds to worm-based attacks against military networks, provides advanced warning to other DoD enterprise networks, studies and determines the worm's propagation and epidemiology, and immunizes the network automatically from these worms. The final system will quickly quarantine zero-day worms to limit the number of machines affected, as well as restore the infected machines to an uncontaminated state in minutes, rather than hours and days, which is today's state of the art.

Normally, large, homogeneous networks are quite vulnerable to cyber attack: if all the network computers have identical operating systems and software, then a software vulnerability or fault in any one component can make the entire network vulnerable to catastrophic disruption. However, the vision of the Application Communities program is to turn network size and homogeneity into advantages. By sharing knowledge about attacks, bugs and possible recovery strategies, a community of commercial off-the-shelf systems could use automated actions to prevent the spread of problems to other systems and restore normal function.

At the hardware component level, our network and computer security requires that the microelectronics from which they are built can be trusted, particularly when more and more of those electronics may be purchased from around the globe. DARPA's TRUST program is seeking ways to determine if malicious features have been inserted during the design or fabrication of application specific integrated circuits, or if malicious features might have been inserted during the loading of field programmable gate arrays. DARPA is at the forefront of research in this area, addressing these issues in a comprehensive manner for the first time.

Finally, we must be able to carefully test how all these systems come together. Rapid technical progress often requires development of precise tools and testbeds for rigorous experiments and validation. DARPA is taking the lead in improving experimentation for information assurance by leveraging its research experience to develop a National Cyber Range that will allow realistic, quantifiable tests and assessments of cybersecurity scenarios and technology. The range will contain thousands of real and virtual nodes, managed by revolutionary test and resource configuration and management suites, to provide realistic, tailored simulations of large-scale military and government networks, all coupled with state of the art forensic tools to analyze exactly what happens. The revolution in large-scale cyber testing created by the National Cyber Range will spur tremendous progress in making military networks more secure and reliable in the face of a wide range of challenges.

3.2. Detection, Precision ID, Tracking, and Destruction of Elusive Targets

For many years, the Department of Defense has steadily improved its ability to conduct precision strike against both stationary and moving ground targets. The timely, accurate and precise delivery of bombs and missiles has given the U.S. military tremendous advantages. In recent years, America's adversaries have realized that if they are to survive the United States' superior precision strike capabilities, they either have to move, hide, or blend-into cluttered environments. U.S. combatant commanders consistently cite the critical need for an improved ability to find and track these illusive targets.

It is still difficult to detect, identify, track, and strike targets that are hiding, use evasive tactics such as frequent starts and stops, or that require a rapid reaction by U.S. forces in order to be destroyed.

To provide a focused response to these challenges, DARPA is assembling sensors, exploitation tools, and battle management systems to rapidly find, track, and destroy irregular forces that operate in difficult terrain. This includes small-units operating in mountains, forests, and swamps; ground troops that abandon open country for cities; and insurgents whose whole organization – finance, logistics, weapon fabrication, attack – is embedded in civilian activities. DARPA is even looking out to sea to counter the piracy threat.

To do this, we must seamlessly layer surveillance and battle management systems using a network of platforms that provide both capable sensors and effective weapons (Figure 15).

For example, changes detected between images generated by DARPA's foliage-penetrating radar can be used to engage elusive targets. The radar operates at frequencies that penetrate the forest canopy. Algorithms, running either on an aircraft or by the network at a ground station, compare images taken at different times to detect changes that signify either departures or arrivals. Because radars operate in all weather and at long ranges, this technique can discover the location of potential targets over very wide areas.

DARPA successfully demonstrated a foliage penetrating radar that detects vehicles and dismounted troops moving under heavy forest canopy. The radar, called FORESTER, was

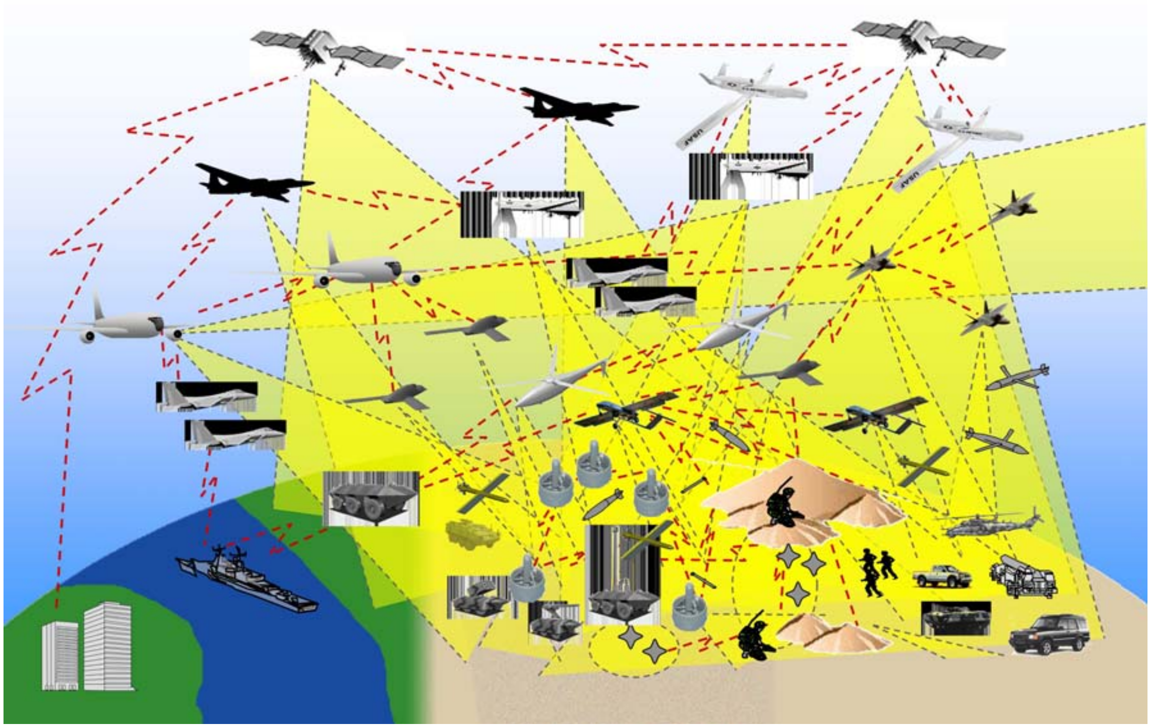

Figure 15: Networked operations.

installed on a Black Hawk helicopter, which flew at a standoff range. Operators onboard the aircraft were able to detect people walking under foliage in and around concealed encampments.

DARPA is also networking radars together. DARPA's NetTrack program uses airborne radars to gather features of moving vehicles and pass that information over a network to maintain tracking information over extended periods. This network of radars will allow us to track the enemy even if they move behind obstructions or into urban canyons.

To identify targets in response to these cues, DARPA has developed ladar sensors that can obtain exquisitely detailed, 3-D imagery. Figure 16 shows a ladar image of a tank beneath forest cover. By flying the ladar over a potential target, photons can be collected from many different angles. Those that pass through gaps between leaves, however few, can be collated together into a composite image. New computational methods can match these data against 3-D geometric models of a variety of target types, even identifying gun barrels, rocket launchers, and other equipment that unambiguously indicate the military nature of the vehicle (Figure 16 depicts actual data from field tests).

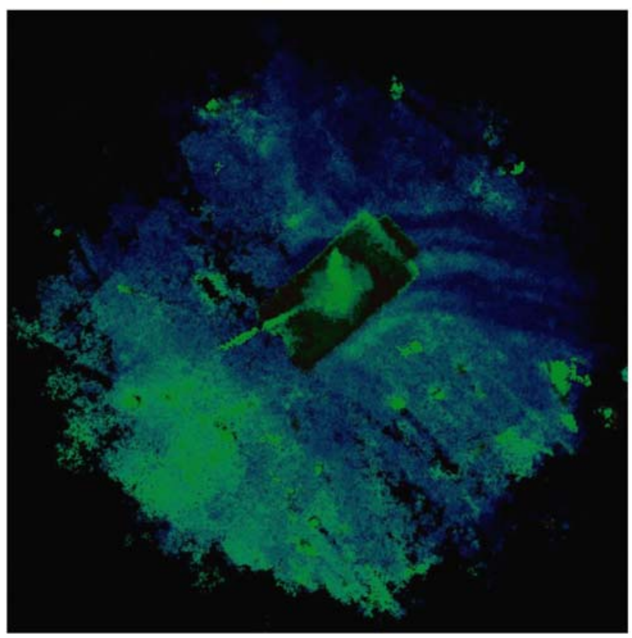

Figure 16: A composite image of a tank under trees formed from observations by a ladar sensor.

DARPA is developing software tools to "stitch-together" and cross-cue information

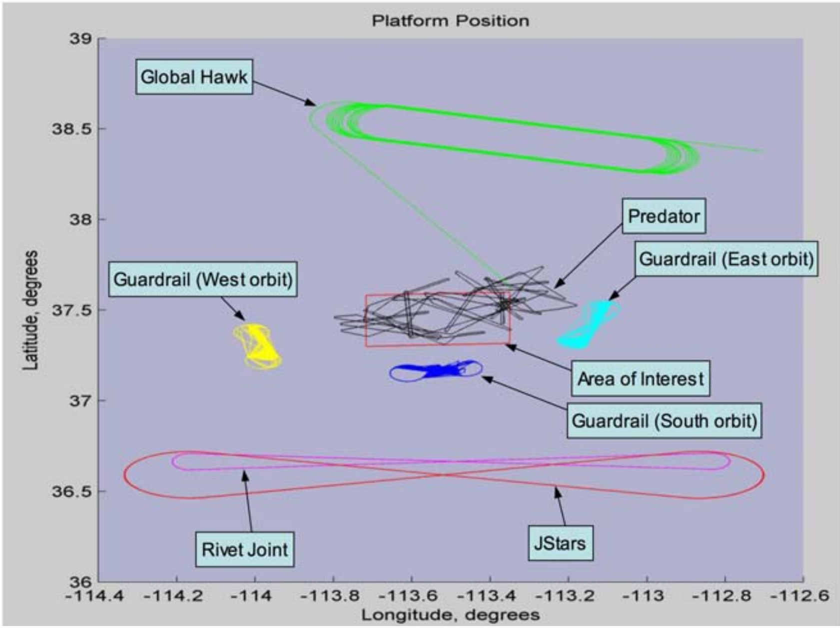

Figure 17: Decision aids help manage and adjust sensor routes to cover moving targets.

obtained from a variety of tactical sensors (e.g., moving target indicator radar, synthetic aperture radar, optical, video, and acoustic sensors), and then cue the sensors to obtain more information (Figure 17). For example, the change detections obtained from radar could cue the ladar sensor to watch a new arrival. Conversely, if Predator video lost a target because it entered a forest, the radar could be cued to search for the vehicle.

And to better understand vessel behavior and detect threats at sea, DARPA's Predictive Analysis for Naval Deployment Activities (PANDA) program is developing technology that exploits surface maritime vessel tracks to automatically learn the normal behavior of over 100,000 vessels, and then detect deviations. PANDA will automatically provide alerts on those vessels exhibiting suspicious activity, including activities that have not been previously seen or defined.

3.3. Urban Area Operations

By 2025, nearly 60 percent of the world's population will live in urban areas, so DoD must assume that U.S. forces will continue to be deployed to urban areas for combat and post-conflict stabilization. Unstable and lawless urban areas give terrorists sanctuary to recruit, train, and develop asymmetric capabilities, possibly including chemical, biological, and radiological weapons of mass destruction.

Urban area operations can be the most dangerous, costly, and chaotic forms of combat. Cities are filled with buildings, alleys, and interlocking tunnels, which provide practically limitless places to hide, store weapons, and maneuver. They are hubs of transportation, information, and commerce, and they are homes for a nation's financial, political, and cultural institutions. Cities are densely packed with people and their property, creating an environment in which adversaries can mix in and use civilians as shields to limit our military options. And insurgents don't just mix in, they *blend* in.

Warfighting technology that works superbly in the open or in the rugged natural terrain of the traditional battlefield is often less effective in cities. By moving into cities, our adversaries hope to limit our advantages, draw more of our troops into combat, inflict greater U.S. casualties, and cause us to make mistakes that harm civilians and neutrals.

The Urban Area Operations thrust is aimed at creating technology to help make U.S. operations in cities as effective as operations in non-urban areas by seeking new urban warfare concepts and technologies that would make a smaller U.S. force conducting operations in an urban area more effective, suffer fewer casualties, and inflict less collateral damage.

Improved urban intelligence, surveillance, and reconnaissance

DARPA has several programs to vastly improve U.S. capabilities to understand what is going on throughout a complex urban environment, including the ability to detect adversaries hiding in buildings and other structures, and to find hidden explosives or weapons of mass destruction.

DARPA's UrbanScape system will rapidly create a three-dimensional model of an urban area that allows the user to navigate and move around in a computer environment much like a video game, but one based on real data. This will allows troops to become very familiar with the urban terrain before beginning a mission. DARPA is also developing technologies that allow ground troops to easily share intelligence information they have collected themselves with other troops in order to plan missions more accurately, safely and quickly.

DARPA is working to improve our warfighters' ability to see in the urban environment. A helmet-mounted visor is being developed that displays a fused image created from several other helmet-mounted sensors – even when it's too dark for night vision goggles, or when peering through smoke and fog. And DARPA developed a hand-held radar that senses people on the other side of walls to detect potential enemies before warfighters enter a room or building.

Moving up from ground level, DARPA is developing ARGUS-IS, a new wide field-of-view video sensor designed for the A160 unmanned aircraft, that significantly increases the number of targets tracked in the urban environment. The sensor will provide over 65 real-time, high-resolution video windows, *each one* providing motion video comparable to Predator imagery.

The backpackable Wasp micro air vehicle, a squad-level surveillance and reconnaissance asset that enables small units to quickly view their immediate, local terrain is DARPA's signature program in aerial urban sensing, and has gained the distinction of being the first micro air vehicle to be adopted by the U.S. armed forces in an acquisition program, the Air Force's Battlefield Air Targeting Micro Air Vehicle. Based on our Wasp micro air vehicle, DARPA is creating an entirely new generation of perch-and-stare micro air vehicles capable of flying to difficult targets, landing, perching, conducting sustained surveillance, and then re-launching from its perch and returning home.

Working with the Marine Corps

DARPA continues to work diligently in collaboration with the Marine Corps to satisfy current, emerging, and future warfighting needs. Today, Marine forces forward-deployed in the Global War on Terror (GWOT) are more effective because of visionary DARPA-sponsored technology, pulled from the Far side and made ready to fill urgent needs in Iraq, in Afghanistan, and in every clime and place. Marine small infantry units are operating with greatly increased situational awareness because of the Wasp micro air vehicle. They are more survivable because of the Generation II Boomerang shot detection system and the Bar Armor rocket propelled grenade protection kits. And Marines are more effective in counter insurgency and irregular operations because they have developed increased cultural awareness and language proficiency through Tactical Iraqi.

The future needs of the Marine Corps are established in the Marine Corps Science and Technology Strategic Plan. DARPA is collaborating at every level to bridge the gap and accelerate the technology required to fulfill the Marine Corps' Science and Technology Objectives (STOs). DARPA has multiple programs designed to lighten the load of individual Marines, to provide relevant all source information out to the tactical edge, to increase survivability, and to ensure precise and lethal engagement. Working with Marines at all levels, DARPA continually aligns programs with future capability gaps and informs Marine Corps' senior leaders of game-changing technologies that could lead to new operational constructs. The Commandant has challenged his Corps of Marines to prepare for tomorrow's challenges today; DARPA is answering the challenge.

Tagging, tracking and locating capabilities

DARPA has been developing new capabilities to persistently monitor targets or equipment of interest; tag, track and locate enemy activities; track and detect weapons fabrication and movement; and precisely discriminate threat from non-threat entities against severe background clutter.

Asymmetric warfare countermeasures

Protecting our warfighters from asymmetric attacks is an ever-present challenge – especially in the close-quarters and congestion of cities. DARPA is developing technologies to detect, prevent, or mitigate asymmetric attacks, including suicide bombers, improvised explosive devices, and weapons of mass destruction.

Improvised explosive devices (IEDs) remain a significant threat to our forces in Iraq and Afghanistan. DARPA's Hardwire program has developed an entirely new class of armor that weighs less than comparable steel armor and has demonstrated outstanding protection against armor piercing rounds, fragments, and IEDs.

Small arms fire poses a constant threat, particularly in urban terrain. DARPA's low-cost Boomerang shooter detection and location system provides a new force protection tool that warns ground forces when they are being fired upon and where the fire is coming from. Hundreds of vehicle-mounted and stationary units are now being employed in theater, and additional orders are being fulfilled. Building on the success of Boomerang, DARPA is developing a detection and warning system for ground forces under the Crosshairs program, which incorporates the Boomerang system as well as an advanced radar capable of detecting a broad range of threats including small arms, rockets, missiles, and mortars.

Pre- and post-conflict capabilities

DARPA programs are modeling and understanding social indicators that precede the onset of hostilities and conflict, coupled with tools to develop strategies to stabilize an urban area and assist U.S. civil affairs units.

One DARPA program will help combatant commanders anticipate and respond to security risks in their areas of operations by developing new technologies to take in raw political, economic, social, and media data and automatically convert it into actionable information that reflects the character and intensity of interactions between key leaders, organizations and countries, and provides indicators of instability and forecasting capability.

To improve our training, DARPA's RealWorld program will provide U.S. troops with the ability to rehearse a real world mission using a laptop computer. The program is creating technology that will allow troops to build their own mission simulations rapidly and easily. This will allow warfighters to build simulations themselves, without needing programmers, saving a tremendous amount of time, money and manpower while getting simulations that are better tailored to the user. And because the system will be scalable and distributed, warfighters can practice by themselves, in small groups, or with as many other warfighters as needed for the mission over a local or distributed network, and across all relevant platforms (for example, dismounts, vehicles, helicopters, fast movers).

DARPA's Conflict Modeling, Planning, and Outcomes Experimentation program is developing a suite of tools that will help military commanders and their civilian counterparts to plan, analyze and conduct lengthy and large-scale campaigns. The program carefully considers, and weighs the ramifications of not only traditional military actions, but also of political, social, and economic activities and initiatives. The program allows the user to carefully consider and weigh the ramifications of traditional military actions as well as political, social, and economic factors.

Command, control, communications, and intelligence (C3I) for urban warfighting

Operating effectively, safely, and with a minimum of collateral damage in cities requires developing new approaches to all-echelon command and control, and new intelligence analysis tools specifically suited for urban operations that allow warfighters to see and understand what is happening throughout the urban battlespace in real time.

DARPA's Coordination Decision-Support Assistants program has created new software focused on tactical operations that will enable each warfighter and commander to have a decision support assistant that helps to adjust plans in real-time as the tactical situation changes and plans must be modified, freeing the warfighters to concentrate on the enemy and the battle.

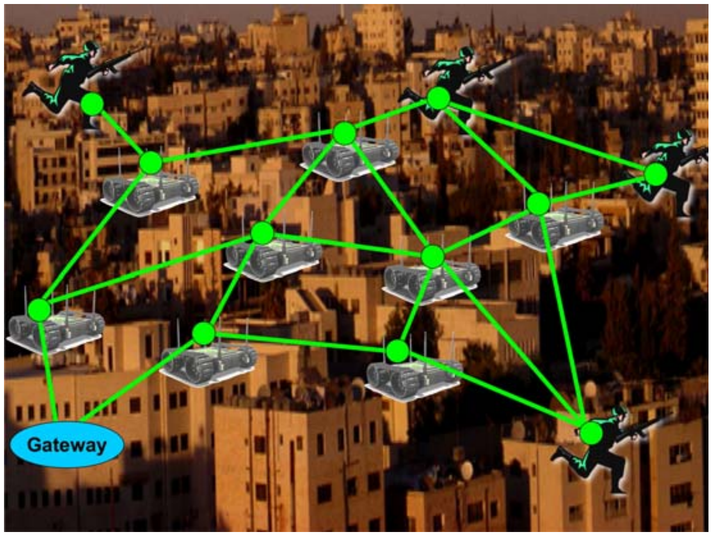

Figure 18: LANdroid concept of operations.

And our LANdroids program will assist urban communications by creating small robots ("LANdroids") that are also communications relay nodes that establish and manage communication networks. Warfighters will carry several of these pocket-sized LANdroids, dropping them as they deploy (Figure 18). The LANDroids will "talk" to one another and spread out to establish a mesh communications network over the region. When the warfighters move, the LANdroids and the network will move with them to maintain robust, self-healing communications.

3.4. Advanced Manned and Unmanned Systems

DARPA is working with the Services and USSOCOM toward a vision of a strategic and tactical battlespace filled with networked manned and unmanned air, ground, and maritime systems, and the technologies they need to navigate and fight. Unmanned systems provide autonomous and semiautonomous capabilities that free Soldiers, Sailors, Airmen and Marines from the dull, dirty, and dangerous missions which might now be better done robotically, and they enable entirely new design concepts unlimited by the endurance and performance of human crews. The unmanned aerial vehicles in Afghanistan and Iraq have been demonstrating this transformational potential.

DARPA's efforts have been focused in two areas. First, DARPA seeks to improve individual platforms so that they provide new or improved capabilities, such as unprecedented endurance or survivability. Second, DARPA is expanding the level of autonomy and robustness of robotic systems. Progress is measured in how well unmanned systems can handle increasingly complex missions in increasingly complicated environments (Figure 19). Autonomy and robustness are improved by more tightly networking manned and unmanned systems to improve our knowledge of the battlespace, enhance our targeting speed and accuracy, increase survivability, and allow greater mission flexibility.

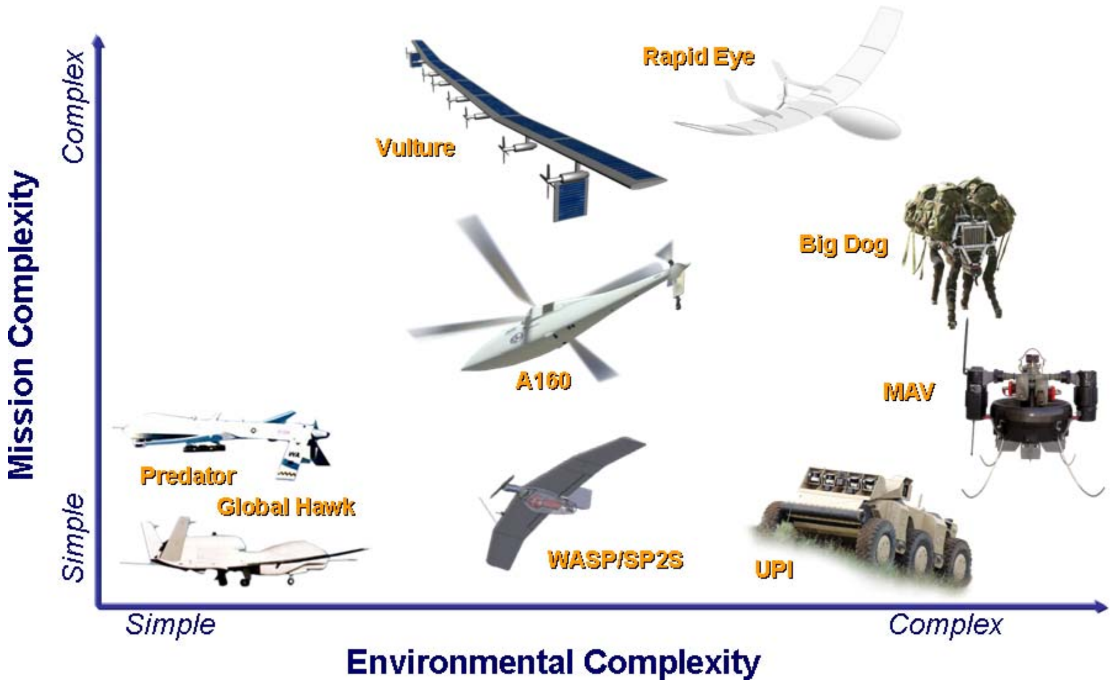

Figure 19: Unmanned Vehicles – the increasing challenge of autonomy.

Our A160 program (Figure 20) is developing an unmanned helicopter for intelligence, surveillance, and reconnaissance (ISR) missions, with long endurance – up to 20 hours – and the ability to hover at high altitudes. In 2008, the A160 set a world record for UAV endurance when it completed an 18.7 hour endurance flight. The A160 concept is being evaluated for surveillance and targeting, communications and data relay, crew recovery, resupply of forces in the field, and special operations missions in support of Army, Navy, Marine Corps, and other needs.

Figure 20: A160 long endurance unmanned rotorcraft demonstrating a 1000 pound payload carriage capability over a distance of 962 kilometers during an eight hour flight in September 2007.

Vulture (Figure 21) will develop an aircraft capable of remaining on-station for over five years, pushing technology and design so that the system may not require refueling or maintenance. A single Vulture aircraft could support traditional intelligence, surveillance, and reconnaissance functions over country-sized areas, while also providing geostationary satellite-class communication capabilities but at a fraction of the cost. Vulture's challenges include developing solar cell, energy storage, and reliability technologies that will allow it to operate continuously, unrefueled, for over 44,000 hours. The program will culminate in a year-long flight demonstration.

DARPA's Rapid Eye program is creating the capability to deliver a persistent intelligence, surveillance, and reconnaissance asset anywhere worldwide within one to two hours. The program will develop a high-altitude, long-endurance, unmanned aircraft that can be put on existing space launch systems, withstand atmosphere re-entry, and provide efficient propulsion in a low-oxygen environment at low speed.

The Tango Bravo technology demonstration program is exploring technology options for a reduced-size submarine with capability equivalent to the VIRGINIA Class submarine. This program is developing technologies aimed at reducing platform infrastructure, specifically by reconfiguring the submarine with shaftless propulsion, external weapons stowage and launch, and ship infrastructure reduction technologies that eliminate or simplify hull, mechanical, or electrical systems. These improvements afford greater payload volume and reduce the cost of design and production of future submarines.

Just as air vehicles have moved toward both increased mission complexity and increased environmental complexity, DARPA is also trying to increase both the mission and environmental complexity for autonomous ground vehicles. This will help meet the Congressional goal that, by 2015, one third of U.S. operational ground combat vehicles will be unmanned.

The Unmanned Ground Combat Vehicle – Perception for Off-Road Robotics (PerceptOR) – Integration (UPI) program demonstrated an

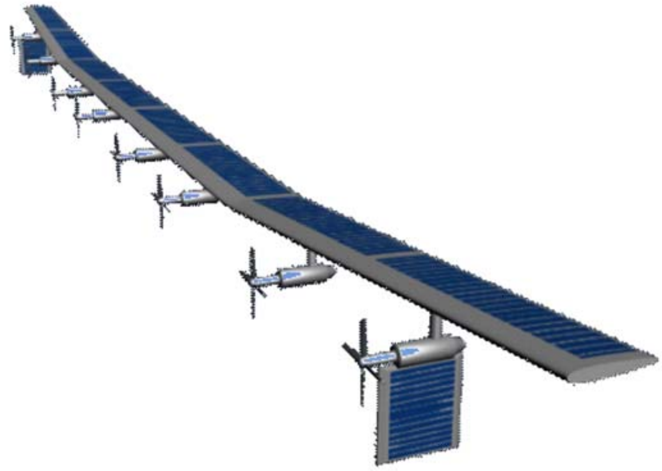

Figure 21: Vulture ultra-long endurance aircraft.

Working with the Army

DARPA and the Army have built a solid relationship through senior leadership exchanges and program reviews, including visits with the Secretary of the Army and Chief of Staff of the Army, quarterly exchanges through the Army-DARPA Senior Advisory Group, and periodic visits by the Commanders of Training and Doctrine Command (TRADOC) and Army Materiel Command. These meetings have led to a number of developments aimed at assuring the United States Army maintains a technologically decisive advantage over its adversaries. The Army also participates in DARPA's Service Chiefs intern program by providing qualified officers from throughout the Army and TRADOC.

In the past few years, the Army has benefited from a number of DARPA developments. Advanced acoustic sensors were issued to units in Iraq and Afghanistan to provide troops in light-skinned vehicles warning of hostile fire. DARPA technology supported the Army's Future Combat Systems Unmanned Aerial Systems spinouts with the development and fielding of the Micro Air Vehicle. Programs like the Command Post of the Future, Bar Armor, and the Tactical Ground Reporting System (TIGR), are currently supporting Soldiers in Operations IRAQI FREEDOM and ENDURING FREEDOM. DARPA is developing technologies in other areas to support Army Warfighters, including Counter-Improvised Explosive Device programs, enhanced soldier optics, battle command connectivity, improved wide-area surveillance, airspace coordination and deconfliction tools, and enhanced trauma care. A number of programs in these categories have matured and are nearing transition.

At present, DARPA is working with the Army to match technologies to needed capabilities from their Warfighter Outcomes. Support to the Army's Future Modular Force includes improvements in armor, battle command, aerial and ground unmanned systems, power and energy, force protection, and medical care.

unmanned ground vehicle (UGV) capability by putting perception and the use of terrain data for path planning on an extremely capable robotic vehicle. DARPA has begun to transition this technology to the Army, and provided a prototype ground vehicle with PerceptOR vehicle control algorithms and software to the Army Tank-Automotive Research, Development and Engineering Center to use in developing a UGV control architecture, and conducting vehicle design and control risk mitigation activities for Future Combat Systems (FCS) UGVs. In addition, UPI's perception and planning control and sensor algorithm suite has been transitioned to the FCS Autonomous Navigation Sensor program.

DARPA held a series of prize competitions in 2004-2007 to rapidly promote the development of ground vehicles that are entirely under computer control and can negotiate difficult terrain without a human driver. The capstone event was the Urban Challenge, in which DARPA used what it had learned in the two open desert "Grand Challenges" to lay out a far more difficult challenge: autonomous ground vehicles driving at-speed in urban traffic, obeying driving rules and regulations, and interacting with other manned and unmanned vehicles. In the first large-scale test of its kind, the Urban Challenge featured autonomous ground vehicles maneuvering in a mock city on simulated military supply missions (Figure 22).

Figure 22: Tartan Racing's (Carnegie Mellon University) "Boss," the first place finisher in the DARPA Urban Challenge, on the course.

From the initial field of 89 applicants, Tartan Racing's (Carnegie Mellon University) "Boss" of Pittsburgh, Pennsylvania, turned in the top performance, winning the $2 million cash prize as the competition's first-place winner. Stanford Racing's (Stanford University) "Junior" of Stanford, California, won the $1 million second place prize, while Victor Tango's (Virginia Tech) "Odin" of Blacksburg, Virginia, received $500,000 for finishing third.

3.5. Detection, Characterization, and Assessment of Underground Structures

Our adversaries are well aware of the U.S. military's sophisticated intelligence, surveillance, and reconnaissance assets and the global reach of our strike capabilities. In response, they have been building deeply buried underground facilities to hide various activities and protect them from attack.

These facilities can vary from the clever use of caves to complex and carefully engineered bunkers in both rural and urban environments (Figure 23). They can be used for a variety of purposes, including protecting leadership, command and control, hiding artillery and ballistic missiles launchers, and possibly producing and storing weapons of mass destruction.

To meet the challenge posed by the proliferation of these facilities, DARPA is developing a variety of sensor technologies and systems – seismic, acoustic, electromagnetic, optical, and chemical – to find, characterize, and conduct post-strike assessments of underground facilities. Specifically, the program is working on tools to answer the questions, "Where is the facility? What is this facility's function? What is the pace and schedule of its activities? What are its layout, construction, and vulnerabilities? How might it be attacked? Did an attack destroy or disable the facility?"

Figure 23: Cave entrance.

To answer these and other questions, DARPA is developing ground and airborne sensor systems (Figure 24) with two-orders-of-magnitude improvement in sensor system performance, with emphasis on advanced signal processing for clutter rejection in complex environments.

Figure 24: Underground facility detection and characterization.

For example, DARPA's Airborne Tomography using Active Electromagnetics program is developing an active electromagnetic system for airborne imaging of subsurface structures, such as underground facilities or perimeter-breaching tunnels. Building on technology from geophysical exploration, the system will illuminate the ground with electromagnetic energy and interpret the resulting distortions of the electric and magnetic fields to detect and characterize surreptitious structures.

While large, developed facilities have long been recognized as strategic threats, there is increasing need to find and characterize small underground structures. These include caves that serve as hiding places and tunnels for smuggling weapons and infiltrators across borders. Caves and tunnels provide secret entry into sensitive areas, such as Baghdad's International Zone, and may even contain prisons or weapons laboratories.

DARPA's Cross-Border Tunnel program has been working to detect small tunnels used to breach security perimeters and national borders by developing technologies that detect and characterize those tunnels, while simultaneously satisfying operational considerations such as search rate, site access, and exposure of friendly forces.

3.6. Space

The national security community, and the U.S. military in particular, use space systems for weather data, warning, intelligence, communications, and navigation because they provide great advantages over potential adversaries. American society as a whole uses space systems for many similar purposes, making them an integral element of the U.S. economy and way of life.

These advantages – and the dependencies that come with them – have not gone unnoticed, and there is no reason to believe they will remain unchallenged or untested forever. As the Rumsfeld Commission explained, "An attack on elements of U.S. space systems during a crisis or conflict should not be considered an improbable act. If the United States is to avoid a 'Space Pearl Harbor,' it needs to take seriously the possibility of an attack on U.S. space systems."[8]

DARPA began as a space agency, when the shock of Sputnik caused Americans to believe the Soviet Union had seized "the ultimate high ground." DARPA maintains an ambitious effort to ensure that the U.S. military retains its preeminence in space by maintaining unhindered U.S. access to space and protecting U.S. space capabilities from attack. Figure 25 depicts DARPA's space strategic thrust with five elements:

- *Access and Infrastructure:* technology to provide rapid, affordable access to space and efficient on-orbit operations;
- *Situational Awareness:* the means for knowing what else is in space and what that "something else" is doing;
- *Space Mission Protection*: methods for protecting U.S. space assets from harm;
- *Space Mission Denial:* technologies that will prevent our adversaries from using space to harm the U.S. or its allies; and
- *Space-Based Support to the Warfighter*: reconnaissance, surveillance, communications, and navigation to support military operations down on earth – extending what the United States does so well today.

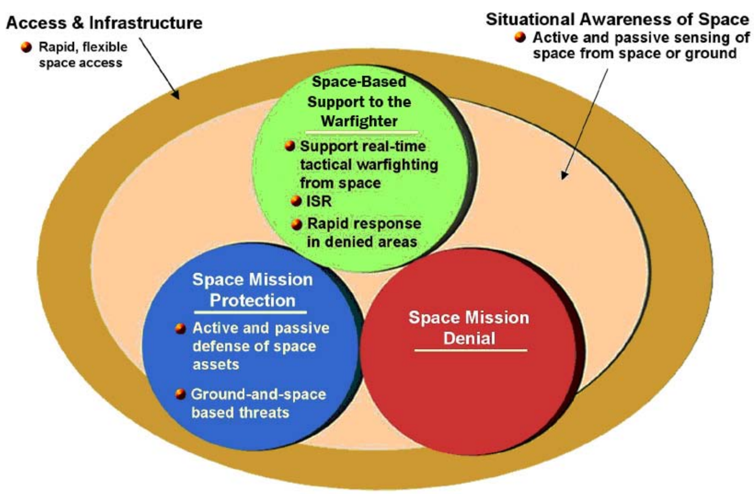

Figure 25: DARPA's space thrust.

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8 Honorable Donald H. Rumsfeld, Chairman, Rumsfeld Commission, *Report of the Commission to Assess United States National Security Space Management and Organization* (January 11, 2001).

Figure 26: Falcon hypersonic technology vehicle (HTV).

The Falcon program (Figure 26) has been working to vastly improve the U.S. capability to promptly reach other points on the globe. A major goal of the program is to flight-test key hypersonic cruise vehicle technologies in a realistic flight environment. Recently DARPA conducted both low- and high-speed wind tunnel tests that validate the stability and control of the hypersonic technology vehicle (HTV) across the flight regime. Two HTV test flights are planned from Vandenberg Air Force Base to Kwajalein Atoll to test thermal and aerodynamic control systems. One flight will follow a fairly direct trajectory, while the second "buttonhook" trajectory will demonstrate significant cross-range maneuver capability.

Propellant on-board today's spacecraft is limited to the amount carried at launch. This reduces the useful payload on orbit because significant fractions of launch mass are to provide a lifetime of on-orbit fuel. Limited fuel also constrains on-orbit maneuvering, reducing the ability to relocate spacecraft in response to new needs or threats. In short, the inability to refuel spacecraft limits their lifetime.

DARPA's Orbital Express program showed how on-orbit satellite operations could fundamentally change by demonstrating the ability to refuel satellites and replace their electronics on-orbit, offering a way to dramatically improve the life span, maneuverability, and self-protection of orbiting satellites. Over 135 days, two satellites, NextSat and ASTRO, performed increasingly complex tasks, demonstrating autonomous rendezvous from up to 200 kilometers, as well as the ability to conduct autonomous proximity operations including refueling, electronics replacement, and circumnavigation.

Working with the Air Force

DARPA and the Air Force continue to enjoy a very strong and productive relationship. Over the past year, DARPA fostered a particularly close and productive relationship with the Air Force Space Command, Air Combat Command, Air Mobility Command, Air Force Special Operations Command and Air Force Security Forces. DARPA also relied on its close business relationship with the Air Force S&T community, especially with the Air Force Research Laboratory who continues to act as agent for many DARPA programs. These relationships led to several new DARPA programs in space, networking, unmanned aerial systems, sensors and intelligence, surveillance and reconnaissance. DARPA's key technological thrusts benefitted all three of the USAF's prime mission areas: air, space and cyberspace.

DARPA is a key partner in work to improve Precision Strike capabilities. Most recently, we've implemented programs to continually improve our ability to find and track time-sensitive, high-value, mobile targets through several new promising technologies. New breakthroughs of networking will provide near real-time ISR products to the warfighter in addition to decision-makers, planners and targeteers. Another key DARPA program is on the verge of changing the current scheduled aircraft maintenance paradigm to a new model, saving vast amounts of resources and time and keeping combat aircraft flying longer. DARPA is also very active in the development and testing of new directed energy projects and infrared countermeasure endeavors.

The System F6 program (Figure 27) takes a dramatically new approach towards designing, building, launching, and operating larger spacecraft. This program will develop capabilities to decompose a monolithic satellite into an autonomous cluster of individual and physically disconnected modules carrying different payload and subsystem elements. Linked together in a wireless network, this collection of modules creates a "virtual spacecraft." Satellite systems could be repaired or upgraded on demand by placing a new, wirelessly connected module into the cluster. The systems would be robust against attack because the components are physically separated. Using a multiple launch approach, this concept also promises reduced risk from launch failures.

Figure 27: The System F6 space architecture replaces the traditional monolithic spacecraft with a wireless "virtual spacecraft" operating as a cluster of modules

The Space Surveillance Telescope (SST) program will enhance our space situational awareness by demonstrating rapid, uncued search, detection, and tracking of faint, deep-space objects. SST is using curved focal plane array technology to develop a large-aperture optical telescope with very wide field of view to detect and track new and unidentified objects that suddenly appear with unknown purpose or intent, such as small, potentially hazardous debris objects and future generations of small satellites.

With respect to space mission protection, nuclear detonations in low earth orbit present a threat to orbiting satellites. The radiation from a space detonation can be trapped by the earth's magnetic field, increasing the number of energetic particles in the radiation belts and quickly degrading or destroying satellite electronics. The Radhard by Design program will develop design techniques for radiation hardened integrated circuits that can be produced in leading-edge, commercial foundries.

The goal of DARPA's Integrated Sensor Is Structure (ISIS) program is to develop a stratospheric, airship-based, autonomous unmanned sensor with years of persistence in surveillance and tracking of air and ground targets. It will have the capability to track the most advanced cruise missiles at 600 kilometers and dismounted enemy combatants at 300 kilometers. ISIS uses a large aperture instead of high power to meet radar performance requirements, making it the most powerful moving target indicator radar ever conceived.

3.7. Increasing the Tooth to Tail Ratio

U.S. force structure is transforming to operational units that can be rapidly deployed and are flexible and effective across a range of missions, from combat to stability operations. Today's deployed forces require a robust and extensive support infrastructure that is growing even larger. The military sometimes describes the proportion of forces in actual contact with the enemy to the supporting forces as the "tooth to tail" ratio. By using improved information technology, we can reduce the layers and amount of infrastructure (the "tail") needed to operate the computers, software applications, and networks that support the front-line fighting forces (the "tooth"), enabling warfighters to conduct new kinds of missions in new ways. The fundamental goal is to get a larger proportion of our forces into the fight.

From the personal computer to the Internet and beyond, DARPA has been a key catalyst behind much of the information revolution. DARPA is continuing this tradition, focusing on revolutionary new information technologies that will help the U.S. military make better decisions faster and with fewer support personnel.

Figure 28 shows the major themes of this strategic thrust:

- *Cognitive Computing* – Reducing manpower by providing information systems that "know what they are doing" and whose functionality improves through user interactions;
- *High Productivity Computing Systems* – Speeding up the development and deployment of new weapon systems by more complete and rapid design and testing; and
- *Language Processing* – Improving our global operations by removing language and cultural barriers through superb machine language translation, thereby reducing the need for human translators and improving our local knowledge and interactions with the local population.

Theme	Approach
Reduce Manpower and Empower People	Automation Through Cognition
Accelerate Development and Deployment of New Systems	High-Productivity Computing Systems
Global Operations	Language Processing

Figure 28: Major themes supporting enhanced decision-making.

Cognitive Computing

Computer systems are essential to military logistics and planning, command and control, and battlefield operations. However, as computing systems have become pervasive in DoD, they have also become increasingly more complex, fragile, vulnerable to attack, and difficult to maintain. The computing challenges facing DoD in the future – autonomous platforms that behave reliably without constant human intervention, intelligence systems that effectively integrate and interpret massive sensor streams, and decision support systems that can adapt rapidly – will depend on creating more flexible, competent, and autonomous software.

DoD needs revolutionary new computer technology to overcome these challenges. DARPA has embarked on an ambitious mission to create a new generation of computing systems – cognitive computers – to dramatically reduce military manpower and extend the capabilities of commanders and warfighters. Cognitive computing systems can be thought of as systems that "know what they're doing." DARPA's cognitive computing research is developing technologies that will enable computer systems to learn, reason and apply knowledge gained through experience, and respond intelligently to new and unforeseen events.

Success will have enormous benefits for our military. In the real-time environment of military operations, cognitive systems that can learn, reason, and draw on their experience to assist their users will make a huge difference. Cognitive systems will give military commanders and their staffs better access to a wide array of rapidly changing information, reduce the need for skilled computer system administrators, and dramatically reduce the cost of system maintenance.

For example, today's computers handle low-level processing of large amounts of raw data and numeric computations extremely well. However, they perform poorly when trying to turn raw data into high-level actionable information because they lack the capabilities we call "reasoning," "interpretation," and "judgment." Without learning through experience or instruction, our systems will remain manpower-intensive and prone to repeat mistakes, and their performance will not improve. The DoD needs computer systems that can behave like experienced executive assistants, while also retaining their ability to process data like today's computational machines.

The Personalized Assistant that Learns (PAL) program has been developing integrated cognitive systems to act as personalized executive-style assistants to military commanders and decision-makers. PAL is creating a new generation of machine learning technology so information systems automatically adjust to new environments and new users, help commanders maintain the battle rhythm and adapt to new enemy tactics, evolving situations and priorities, and accelerate the incorporation of new personnel into command operations, while making more effective use of resources (Figure 29).

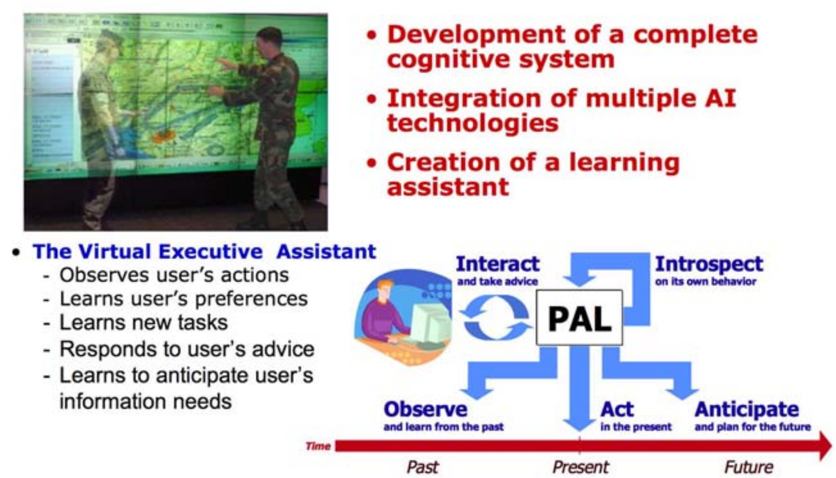

Figure 29: Personalized Assistant that Learns (PAL).

PAL technologies are being implemented in several U.S. defense information management and operations systems. PAL technologies are being used by the Army's Command Post of the Future (CPOF) to amplify the capabilities of overworked combat command and control staffs. Working with CPOF, PAL learns significant battlefield activities, organizes and locates them on maps, and helps users collect information, plan, and execute operations. Evaluations at the Army Battle Command Battle Lab (BCBL) were highly successful. An officer returning from Iraq remarked, "PAL could be an incredibly powerful tool for Tactical Operations Center operations. It has the potential to save countless man-hours by performing routine, repetitive tasks… Those man-hours could then be reallocated to other tasks … or even free up Soldiers to conduct combat operations." In a head-to-head evaluation at the BCBL, a PAL-enhanced CPOF prototype strongly outperformed the current, manually controlled CPOF.

Senior leadership uses the Strategic Knowledge Integration Web (SKIWeb) to share intelligence and to stay abreast of events unfolding throughout the world in real time. SKIWeb uses threaded discussions, or blogging, to share ideas, and encourages collaboration by providing up-to-the-minute situational awareness. PAL learning technology will help SKIWeb recognize and respond to critical event information. Outstanding performance has been demonstrated in an experiment with real SKIWeb data.

Inside command posts, operators perform many complex planning tasks using computers, including developing air tasking order and medical logistics planning. DARPA's Integrated Learning program has demonstrated software that can learn these planning tasks by watching examples. Once the system learns a planning task, it can then support other operators who are perhaps less expert by guiding them through the task. This software will eventually make it practical to create many sophisticated decision support systems that will make our operators faster and more effective at their tasks and help keep our observe-orient-decide-act loops faster than the enemy's.

High Productivity Computing Systems

The High Productivity Computing Systems program is pursuing economically viable, high productivity supercomputing systems for national security and industrial users. The major goal is to produce, by the end of the decade, extremely high performance computing systems that can be easily programmed and used by experts and non-experts alike. These innovative systems will address the difficulties now limiting the productivity of high-end computing systems by emphasizing programmability, portability, scalability, and robustness as well as high

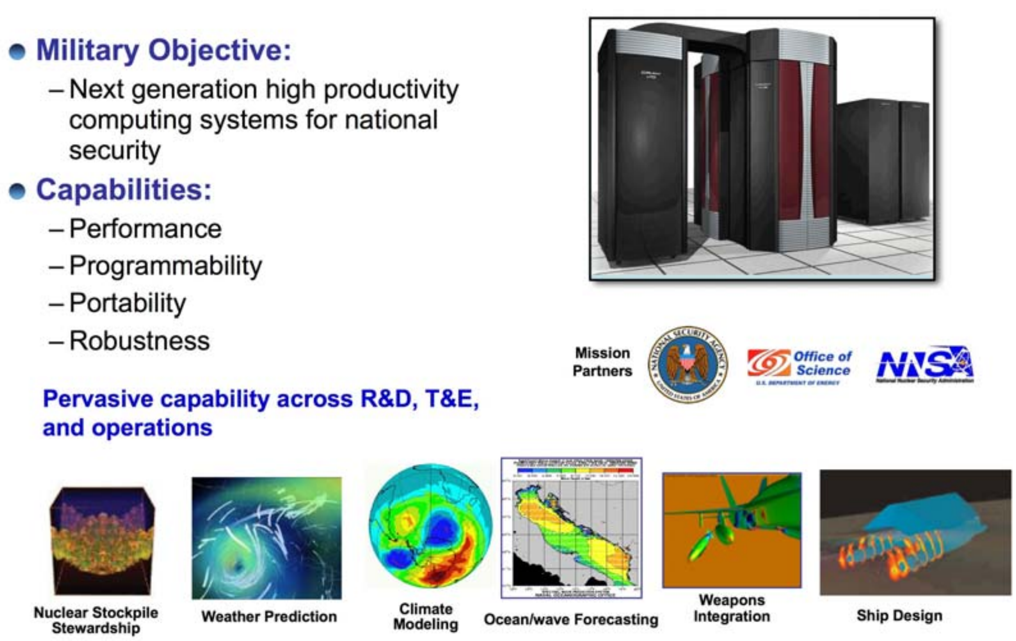

Figure 30: The High Productivity Computing Systems program is pursuing economically viable, high productivity supercomputing systems for national security and industrial users.

performance goals of achieving multiple petaflops and thousands of global updates of memory per second (Figure 30). High productivity computing systems will help design and develop advanced vehicles and weapons, plan and execute military operations, conduct cryptanalysis and image processing, maintain the nuclear stockpile, and generally serve as powerful tools for security-related research.

Language Processing

Improved real-time translation of foreign languages at both the strategic and tactical levels is another important way computers can assist our warfighters. Real-time language translation technology will help U.S. forces better understand adversaries and overall social and political contexts of the operational areas. This improved awareness will decrease costly mistakes due to misunderstandings, and also improve the chances of success.

Today, linguists translate important information, but it is a slow and arduous process. Massive amounts of raw data are being collected, but there are not enough linguists to handle the constant streams of information. To deal with the volume of data and intelligence we capture and receive, we must dramatically reduce the growing reliance on linguists at both the strategic and tactical levels by providing revolutionary machine translation capabilities.

At the strategic level, the goal of the Global Autonomous Language Exploitation (GALE) program is to translate and distill foreign language material (e.g., television shows and newspapers) in near real-time, highlight the salient information, and store the results in a searchable database (Figure 31). Through this process, GALE would be able to produce high-quality answers to the types of questions that are normally provided by bi-lingual intelligence analysts. GALE is making progress toward achieving this very ambitious goal by 2011 (see Figure 32).

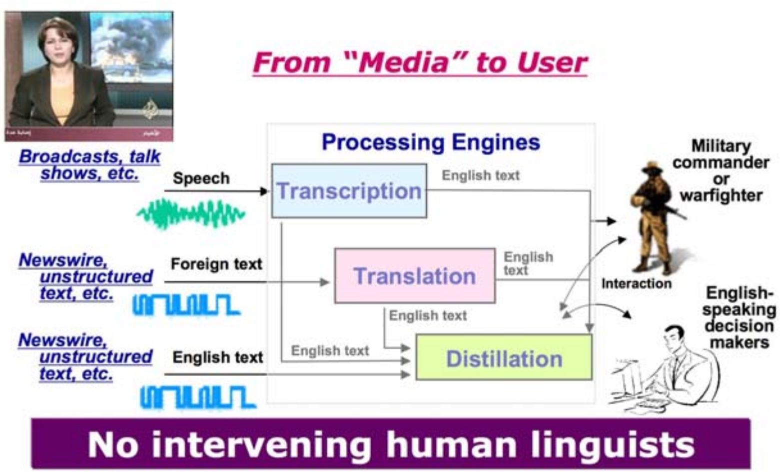

Figure 31: Global Autonomous Language Exploitation.

At the tactical level, there are an insufficient number of translators to support each patrol or vehicle checkpoint. Our warfighters need automatic, on-the-spot speech translation to take advantage of what they may be told by locals and in order to train or conduct missions with Iraqi units. DARPA's Spoken Language Communication and Translation System for Tactical Use (TRANSTAC) program is working on two-way speech translation system to convert spoken foreign language input to English output and vice versa. TRANSTAC works on basic questions and answers about people, medical screening, civil affairs and force protection. Such communication systems will be indispensable for our Soldiers and Marines who work with both the local population and our coalition partners.

DARPA's first Iraqi Arabic speech translation system was prototyped in 2006, and has undergone rapid enhancements. The speeds have improved so that the translated English output is generated only a second or two after the foreign speaker finishes his utterance. One of the goals of the program is to build technology tools to allow working translation systems to be built for new languages in less than 100 days.

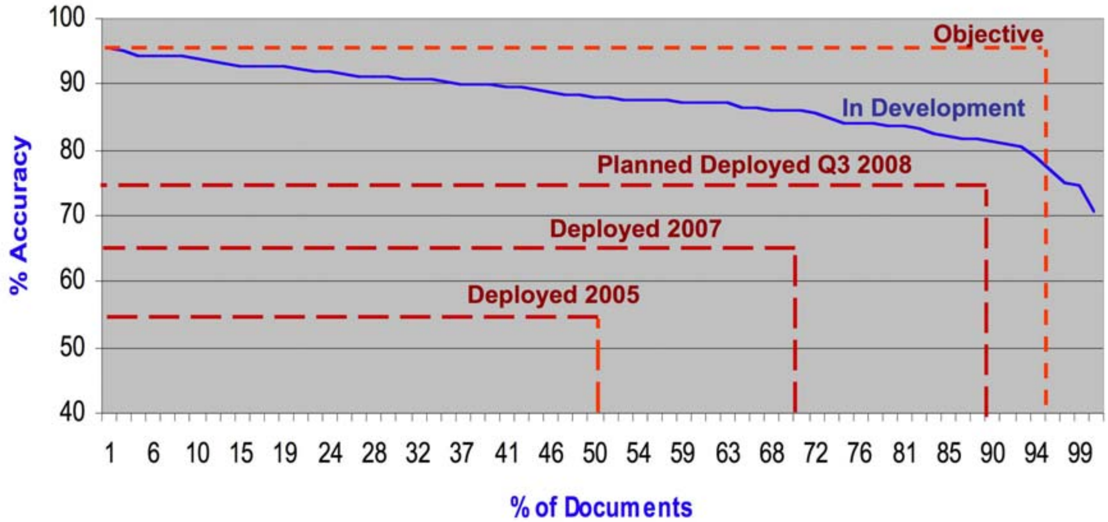

Figure 32: GALE's steadily improving Arabic newswire translation accuracy.

3.8. Bio-Revolution

DARPA's strategic thrust in the life sciences, called Bio-Revolution, is a comprehensive effort to harness the insights and advances of modern biology to make U.S. warfighters and their equipment safer and more effective. The opportunities being investigated in this thrust arise from several developments.

For more than a decade, the United States and many other nations have made enormous investments in the life sciences – so much that it has become commonplace to say that the world is entering a "golden age" of biology. One would be hard-pressed to find a better example of the Far side than the plethora of new discoveries in the life sciences. DARPA is mining these discoveries for technology and concepts that could enhance U.S. national security in revolutionary ways.

The Bio-Revolution thrust has four broad elements.

<u>*Protecting Human Assets*</u>

Advances in biological warfare defense (BWD) will protect warfighters not only from traditional and modern biowarfare agents, but also from the infectious diseases they regularly encounter overseas.

Developing defenses against biological attack poses daunting problems. Strategies using today's technologies to counter future biological threats are seriously limited. First, it is nearly impossible to predict what threats might emerge in two decades, particularly engineered threats. Second, from the moment a new pathogen is first identified – either a weapons agent or a naturally emerging pathogen – today's technology requires at least 15 years to discover, develop, and manufacture large quantities of an effective therapy. It would be exorbitantly costly to attempt to "cover the bases" with the research and development required to deal with a wide range of potential threats, and then stockpile, maintain, and indefinitely renew population-significant quantities of vaccines or other therapeutics just in case one or more of those threats might emerge. And if, in spite of all this, a previously unknown or unpredicted pathogen does appear, there may well be no therapeutics available that are effective against it.

DARPA has been seeking to change the stockpiling paradigm by creating technologies to shrink the time from first pathogen emergence to the production of millions of doses of effective vaccines/therapeutics to *sixteen weeks or less*. DARPA has divided its research along the development timeline in Figure 33:

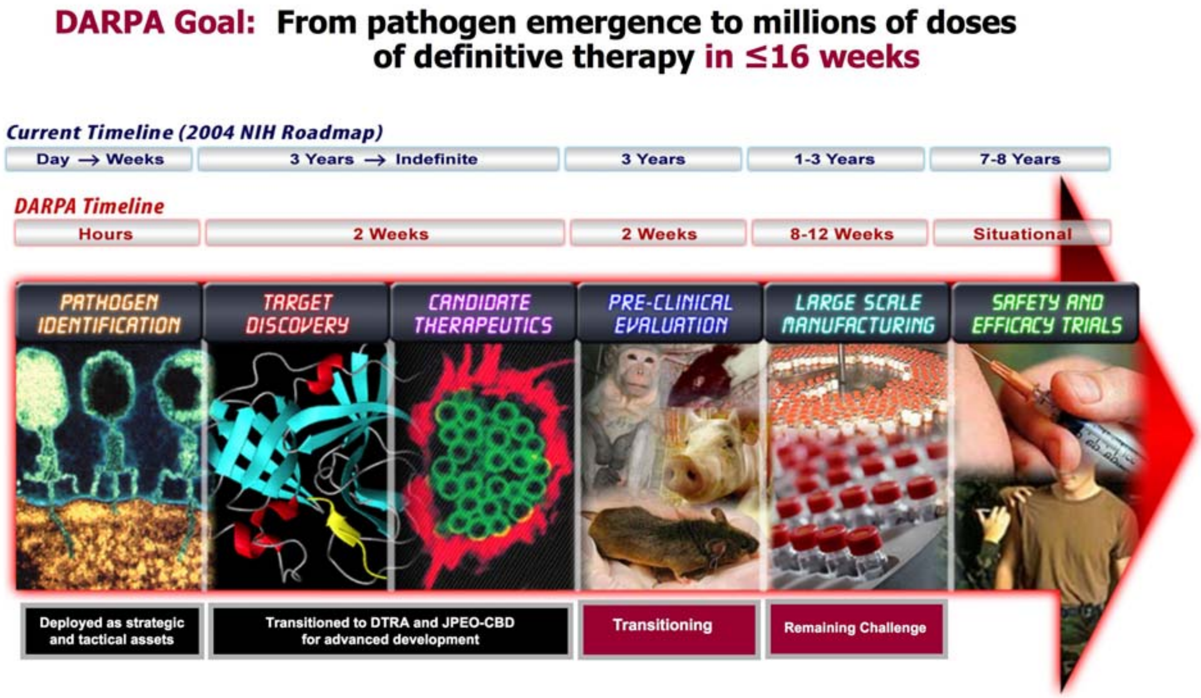

Figure 33: DARPA's timeline for accelerating development of critical therapeutics.

As soon as a BW attack occurs, the first step is to identify and characterize the "bug" ("Pathogen Identification" in Figure 33) so a countermeasure can be developed. DARPA developed a major strategic asset called TIGER[9], which pioneered an entirely new way to identify the DNA of a pathogen and is now fully operational at several facilities.

Once the pathogen has been identified, the next steps are "Target Discovery" and "Candidate Therapeutics" (Figure 33), which were primary focus areas of DARPA's biological warfare defense research from approximately 2000-2005. Target Discovery means finding the "weak spot" in the pathogen against which a therapy can be directed; "Candidate Therapeutics" is actually finding the drug that can attack that weak spot.

Instead of trying to find one target for every new pathogen and then developing a therapy for each, DARPA found common targets among many different pathogens, and then identified common therapies that could take out whole classes of pathogens. While there is no "silver bullet" that can take out all pathogens, there has been substantial progress. For example, DARPA developed a technique to rapidly find common targets among diverse pathogens within weeks. This technique identified a single target weakness common to Ebola, cowpox, and influenza.

DARPA also developed approaches to dramatically increase the effectiveness of vaccines. One agent, CpG, has been shown to reduce the dose required to achieve immunity and the number of

[9] Triangulation Identification for Genetic Evaluation of Risk

"booster shots" required to maintain immunity. With CpG, DARPA demonstrated a nearly nine-fold improvement in response to the anthrax vaccine, and significantly shortened the time until warfighters are fully protected. CpG has transitioned widely and is in advanced clinical trials for influenza and biodefense vaccines.

DARPA's work to discover new therapies include our Protein Design Process program, with the goal to demonstrate a computer-based system that can identify new targets and therapies within 24 hours, in sharp contrast to the weeks or months currently required on a biological "wet bench."

The next step in the timeline is Pre-Clinical Evaluation, which currently requires years of animal testing in a variety of species. Minimizing the requirements for animal testing for all therapeutics is truly a daunting task.

DARPA's Rapid Vaccine Assessment (RVA) program has been developing new ways to test vaccines and rapidly provide more precise, biologically relevant evaluation of human responses than conventional tissue culture systems or animal testing. The RVA-developed platform, MIMIC™ (Model IMmune In vitro Construct), models the human immune system using a high throughput automated system. This platform significantly reduces the time, expense and risk involved with pharmaceutical and vaccine development by providing "human clinical trials in a virtual test tube." MIMIC™ is the first-ever credible method for replacing animal vaccine studies with a safe, accurate approximation of the human immune system. This technology will facilitate rapid screening of candidate vaccines within weeks instead of years, and allow vaccine manufacturers to improve vaccine safety and effectiveness before beginning clinical trials.

Once the vaccine, antibody, or immune enhancer has been identified and undergone pre-clinical evaluation, the next step is to scale up manufacturing, and DARPA's Accelerated Manufacturing of Pharmaceuticals (AMP) program is producing technology for large-scale manufacturing (Figure 33). Instead of the years required to ramp up today's manufacturing practices, AMP technologies combine high-speed natural biological production systems, such as bacteria, fungus and plants, with powerful enabling technologies, flexible bioreactor systems, and automated growth processes to enable rapid and inexpensive manufacture of millions of doses of life-saving drugs or vaccines in weeks on an unprecedented scale.

AMP performers have already demonstrated vaccine production that is six times faster than mammalian cell-based approaches, and capable of producing more than 20 times more protein per liter at dramatically reduced cost. In the case of plants, a hydroponic tobacco growth rack, roughly 14 feet by 10 feet by 10 feet tall, yields sufficient protein for at least one million vaccine doses – replacing three million chicken eggs as a growth medium. This plant approach has also demonstrated the capability to create vaccines that cannot be produced using current egg methods. The plant platform, for example, showed the capability to produce vaccine against a strain of avian flu that cannot be produced traditionally because it is toxic to eggs.

Many challenges remain for discovering effective vaccines rapidly and producing them quickly in large quantities. DARPA's programs have begun to transition technologies to U.S. Government agencies and commercial industries that will enable vaccine discovery to potentially occur orders-of-magnitude faster than we can make happen today, and in population-significant quantities.

"Protecting Human Assets" also means doing everything we can to greatly improve the chances of helping our wounded survive battlefield injury, and DARPA is actively developing advanced combat casualty care technologies.

For combat injuries on the battlefield, hemorrhage continues to be the leading cause of death, accounting for about 50 percent of fatalities. To provide more time for evacuation, triage, and supportive therapies, DARPA's Surviving Blood Loss (SBL) program has been developing novel strategies to delay the onset of hemorrhagic shock due to blood loss by extending the "golden hour" after severe trauma to six to ten hours, or more. SBL is working to understand how energy production, metabolism, and oxygen use is controlled, and to identify protective mechanisms to preserve cellular function despite low oxygen caused by blood loss. SBL has identified very promising compounds, including hydrogen sulfide and estrogen, that, in large animal tests, extend survival from potentially lethal hemorrhage to more than three hours without requiring resuscitative fluids. Human safety trials for hydrogen sulfide are proceeding.

Until recently there were no simple, automated ventilators suitable for the combat medic. Existing field ventilation devices need to be operated by hand, sometimes requiring medics to make a terrible choice between continuing to help someone breathe or leaving that person to treat other casualties. DARPA's SAVe (Simplified Automated Ventilator): Portable Ventilator program developed an automated "Ambu bag" that the combat medic can use in the field that is simple to operate, safe, rugged, and inexpensive. The SAVe ventilator has been deployed with combat medics, and is saving lives today. Because of its compact size, ease of use, and low cost, a modification of the SAVe is being developed that could replace older, more manpower-intensive ventilators used today by civilians.

One of DARPA's long-term efforts to reduce injuries to our warfighters is PREventing Violent Explosive Neurological Trauma (PREVENT), a basic research program looking for the mechanisms of neurological injury – particularly traumatic brain injury – caused by blast. It was thought that peak overpressure was the primary mechanism for blast injury to our troops, but that does not appear to be the case for many of the neurological symptoms in those wounded today by, for example, improvised explosive devices. PREVENT is an aggressive program to fully and scientifically characterize and understand how blasts cause neurological injury, including the cumulative effects on the brain of repeated small blasts that, individually, might not appear harmful. Once the physical mechanisms of neurological injury are understood, specific protective technologies can be designed to protect our warfighters and we can also perhaps develop therapies for those injured.

Biology to Enhance Military Systems

DARPA is creating new systems by developing materials, processes, and devices inspired by living systems. The idea is to let nature be a guide toward better engineering.

For example, our brains are the finest processors of visual imagery that we know of. No machine yet devised even comes close to the brain at visual pattern recognition. DARPA is working to both mimic and better harness this capacity.

The NeoVision2 program is working to understand the fundamentals of the mammalian visual pathway and the brain activity associated with sight and mimic it using state-of-the-art micro-chip designs in silicon-based devices. If successful, the technology will establish a new architecture for image processing and artificial vision devices that might even help restore vision after severe eye injury.

DARPA's Neurotechnology for Intelligence Analysts (NIA) program seeks ways to harness the unique capacity of the brain for visual pattern recognition to vastly improve the productivity of our imagery analysts and allow them to spend more time on actual analysis. DARPA is looking at how the human brain picks out targets in order to create tools to help our analysts spend less time "searching haystacks" and more time using their expertise to understand the changes on the ground.

Today's warfighter must quickly master a large number of diverse skills, from marksmanship to speaking a foreign language. Historically, learning key military skills have been measured qualitatively and subjectively, and often after-the-fact, with little opportunity to redirect learning mid-course. Recent discoveries in neuroscience have laid the foundation for quantitative, neuroscience-based, noninvasive approaches that could dramatically accelerate the transition from novice to expert.

DARPA's Accelerated Learning program is developing approaches for measuring, tracking, and accelerating skill acquisition and learning, that have, in some cases, produced a twofold increase in an individual's progress. For example, working with Marine Corps marksmanship coaches, DARPA has found that there are statistically significant neurophysiological differences between an expert marksman and a novice that can be used to optimize marksmanship training. Similarly, possible ways have been identified to measure progress in learning languages that could be used to tailor language training to the individual, leading to better and faster training than traditional methods.

Maintaining Human Combat Performance

DARPA is working to maintain the warfighter's peak physical and cognitive performance once deployed, despite extreme battlefield environmental stresses such as heat and altitude acclimatization, combined with prolonged physical exertion, and sleep deprivation.

DARPA's Peak Soldier Performance program developed a very simple and completely new technology that can both cool down troops who have become overheated, and warm up troops who have become chilled. The Rapid Thermal Exchange Device takes advantage of the special blood vessels in the palm of one's hand that can readily transfer warmth to or from the bloodstream. The device is a special glove into which one hand is inserted. For overheated individuals, cold water circulates through the grip, rapidly cooling large amounts of blood and maintaining normal body temperature even in extreme heat or during exertion. A modified version of the cooling device is undergoing field testing on Light Armored Vehicles. Another version of the glove is being adapted to maintain body warmth during prolonged underwater diving operations.

One important issue is pain reduction for injured or wounded warfighters. DARPA is developing biodegradable self-regulating drug delivery systems that will enable feedback-regulated release in response to biomarker(s) correlated with drug efficacy and/or toxicity. These systems will enable Soldier self-care through drug delivery methods that guarantee, in the combat environment, a therapeutic dose while eliminating the possibility of overdose.

DARPA researchers have identified a very safe, natural antioxidant called Quercetin, and developed it into a new form that is now available to the military and the general public. Among Quercetin's many potential benefits is maintaining endurance and preventing exercise-induced illness, with no known side effects.

Restoring Combat Capabilities after Severe Injury

Building on our obligation to care for our troops when they are injured entails a longer-term obligation to do the best we can to rehabilitate them. DARPA's goal is to return wounded warriors, as best we can, to who they were before they were injured.

The goal of the Restorative Injury Repair (RIR) program is to fully restore the function of complex tissue, such as muscle, nerves, and skin, after traumatic injury on the battlefield. These injuries include penetrating wounds as well as chemical and thermal burns, and musculoskeletal and blast overpressure injuries. RIR aims to replace nature's process of "wound coverage" by fibrosis and scarring with true "wound healing" by regenerating fully differentiated, functional tissue at the wound site.

Improvements in body armor and medical care have increased the chances of survival, but also have led to more limb amputations. While current prosthetic leg technology is good and improving, prosthetic arm technology, involving so many more joints and movements, as well as the combined abilities to touch, sense, and manipulate fine objects, is much more challenging.

The ultimate goal of DARPA's flagship prosthetics program, Revolutionizing Prosthetics, is to transform upper extremity prosthetics, specifically arms and hands, by developing a prosthetic arm that can be directly controlled by the brain, and which provides the manual dexterity and sensation brain feedback equivalent to a natural hand or arm.

DARPA has been making rapid progress toward this goal. Clinical trials have already begun at Walter Reed and Brooke Army Medical Centers with an intermediate-stage prototype arm that, while not neurally controlled and with less capability than the ultimate goal, is already the best in the world (Figure 34). For some patients who do not need or want a neurally controlled prosthetic, this prototype could constitute a quite satisfactory, practical, and perhaps even preferred long-term solution.

Figure 34: DARPA's revolutionary non-invasively controlled advanced prosthetic, developed under the Revolutionizing Prosthetics 2007 program.

Full clinical trials with completely neurally controlled prosthetics with functions almost identical to natural limbs in terms of motor control and dexterity, sensory feedback, weight, and environmental resilience, are scheduled to begin in two years.

Overall, we want to provide our military upper limb amputees the chance to return to normal life, and perhaps even active duty if they so desire, as quickly as possible.

3.9. Core Technologies

While the eight DARPA strategic thrusts described above are strongly driven by national security threats and opportunities, a major portion of DARPA's research emphasizes areas largely independent of current strategic circumstances. These core technologies are the investments in fundamentally new technologies, particularly at the component level, that historically have been the technological feedstocks for new systems enabling quantum leaps in U.S. military capabilities.

In fact, these technologies often form enabling chains. Advanced materials have enabled new generations of microelectronics, which, in turn, have enabled new generations of information technology, which is the enabling technology for network-centric operations (see Section 3.1).

3.9.1. Quantum Science and Technology

Until recently, quantum effects in electronic devices have not exhibited overriding significance. However, quantum effects not only have to be taken into account, but can dominate how devices perform as they shrink to atomic dimensions. DARPA is sponsoring research aimed at technology exploiting quantum effects to achieve revolutionary new capabilities.

DARPA's Quantum Entanglement Science and Technology (QuEST) program is creating new quantum information science technologies, focusing on loss of information due to quantum decoherence, limited communication distance due to signal attenuation, protocols, and larger numbers of quantum bits (Qubits) and their entanglement. Key among the program's challenges is integrating improved single- and entangled-photon and electron sources and detectors into quantum computation and communication networks. Defense applications include highly secure communications, algorithms for optimization in logistics, highly precise measurements of time and position on the earth and in space, and new image and signal processing methods for target tracking.

3.9.2. Bio-Info-Micro

For the past several years, DARPA has been exploiting and developing the synergies among biology, information technology, and micro- and nanotechnology. Advances in one area often benefit the other two, and DARPA has been active in information technology and microelectronics for many years. Bringing together the science and technology from these three areas produces new insights and new capabilities.

An example is the Fundamental Laws of Biology (FunBio) program. FunBio is working to discover the fundamental laws that govern biological behavior on multiple, interconnected scales – from molecule to cell to organism to population – and to show that such laws can be used to make accurate predictions about biological processes, just as physical theory enables predictions about processes in the inanimate world. The program has already delivered results of enormous potential benefit. New models of viral evolution show that viruses exhibit a wave packet-like species distribution and bank genetic variation in order to escape immune systems. Experiments in bacterial evolution have yielded quantitative methods that can model how organisms evolve along different paths to acquire novel functions. Cyclic growth patterns in plants and animals can be explained in terms of new mathematical models that link gene expression with structural development. Novel analytical techniques applied to physiological data sets are providing insight into new ways to diagnosis diseases. Underlying all of these discoveries is an emerging picture: that environmental pressure under the right set of biological conditions forces a spontaneous and quantifiable change in biological organization. The mathematical expression of this principle may be a key insight unlocking a unified, predictive, theoretical foundation for biology.

3.9.3. Materials

The importance of materials technology to Defense systems is critical and longstanding: many fundamental changes in warfighting capabilities have sprung from new or improved materials. The breadth of this impact is large, ranging from stealth technology, which succeeds partly because materials can be designed with specific responses to electromagnetic radiation, to information technology, which has been enabled by advances in materials for electronic devices.

In keeping with this broad impact, DARPA continues to maintain a robust materials program. DARPA's approach is to push new materials opportunities and discoveries that might change how the military operates. In the past, DARPA's work in materials has led to such technology revolutions as high-temperature structural materials for aircraft and aircraft engines, and the building blocks for the world's microelectronics industry. The materials work DARPA is supporting today builds on this heritage.

DARPA's current work in materials includes the following areas:

- *Structural Materials and Components:* low-cost and ultra-lightweight materials designed for structures or to accomplish multiple performance objectives in a single system;
- *Functional Materials:* advanced materials for non-structural applications such as electronics, photonics, magnetics, and sensors; and
- *Smart Materials and Structures:* materials that can sense and respond to their environment.

For example, the Structural Amorphous Metals (SAM) program is advancing a new class of bulk materials with amorphous or "glassy" microstructures that have previously unobtainable combinations of hardness, strength, damage tolerance and corrosion resistance. Calcium-based SAM alloys are being developed for ultralight space structures, aluminum-based alloys for efficient turbine compressor blades, and iron-based alloys for corrosion resistance in marine environments. In an effort with the Navy, the Naval Advanced Amorphous Coatings program has devised a thermal spray technique that produces textured amorphous metal coatings with a high coefficient of friction and wear, impact, and corrosion resistance that is superior to any other corrosion-resistant, non-skid material, with the goal of certifying them for unrestricted use on Navy ships.

Figure 35: DARPA's Prognosis technology will be demonstrated on a Navy P-3 aircraft.

DARPA's Prognosis program has been developing the science and technology to revolutionize the maintenance of turbine engines. The idea is to do preventative maintenance when physics predicts it is needed, rather than just on a schedule. In 2007, the Air Force and DARPA agreed to transition Prognosis technology into the legacy fleet of turbine engines that power the Air Force's F-15s and F-16s, with the ultimate goal of maximizing engine safety and readiness, while minimizing costs (Figure 35).

3.9.4. Power and Energy

Portable sources of electric power are critical to today's military. To Napoleon's dictum that an Army moves on its stomach, today's modern warfighting forces could add, "…and on energy." Developing portable, efficient, and compact power supplies has important ramifications for increasing our military's reach, decreasing our logistics burden, and improving the overall efficiency of our warfighting forces – especially for distributed and net-centric operations.

One of DARPA's flagship programs here is the Very High Efficiency Solar Cell program, aimed at developing photovoltaic modules with efficiencies over 50 percent, dramatically reducing the dependence of our military bases on petroleum-based fuels and the associated logistics burden.

To help reduce the military's reliance on petroleum-based fuels to power aircraft, ground vehicles, and ships, DARPA's BioFuels program is working to develop an affordable surrogate for military jet fuel (JP8) derived from oil-rich crops such as rapeseed and other plants, algae, fungi, and bacteria. Initial efforts in the BioFuels program have already delivered BioFuel samples that have passed the key JP8 initial qualification tests and whose performance is indistinguishable from petroleum-based JP8. The BioFuels program is expanding the development of processes for cellulosic and algal feedstocks with the ultimate objective of providing for an affordable, diverse supply of military jet fuel.

3.9.5. Microsystems

DARPA is shrinking ever-more-complex systems into chip-scale packages, integrating microelectronics, photonics, and microelectromechanical systems (MEMS) into "systems-on-a-chip" that have new capabilities. It is at the intersection of these three core hardware technologies of the information age where some of the greatest opportunities for DoD arise. By combining elements from the core technologies and using advanced architectures and algorithms, bulky existing systems can be reduced to sugar-cube size, and completely new capabilities can be developed. A key driver for this integration is the spectacular reduction in transistor circuit size under Moore's Law. Electronics that once occupied entire racks now fit onto a single chip containing millions of transistors. Similar gains are achieved by scaling non-electronic components.

DARPA is also exploiting advances in nano-science and nanotechnology, where matter is manipulated at the atomic scale enable still-more-complex capabilities in ever smaller and lower-power packages. DARPA envisions adaptable microsystems for enhanced radio frequency and optical sensing; more versatile signal processors for extracting minute signals in the presence of overwhelming noise and intense enemy jamming; high-performance communication links with assured bandwidth; and intelligent chips that allow a user to convert data into actionable information in near-real-time.

Taken together, these capabilities will create information superiority by improving the ability of the mobile warfighter to collect, process, manage, and act on information – ultimately allowing U.S. forces to think and react more quickly than the enemy in a rapidly changing battlespace

As mentioned above, DARPA's current work in microsystems includes:

- *Microelectronics* – manipulate electrons in digital, analog, and mixed signal circuits for sensing, processing, and communications;

- *Photonics* – generate, detect, and modulate photons for imaging, communications, and sensing;
- *Microelectromechanical Systems (MEMS)* – exploit the processing tools and materials from semiconductor technology to build electro-mechanical structures at the micro- and nano-scale; and
- *Combined Systems-on-a-Chip* – integrate microelectronics, photonics, and MEMS technologies into systems on a single chip.

Microelectronics: DARPA has been pushing to advance microelectronics into three dimensions. Conventional 2-D circuits are limited in performance by the long signal interconnects across ever larger circuits and by existing circuit architectures. Moving to three dimensions (Figure 36) can shorten the signal paths and introduce additional functions in each layer of 3-D stacked circuits that will change the way designers can exploit circuit complexity.

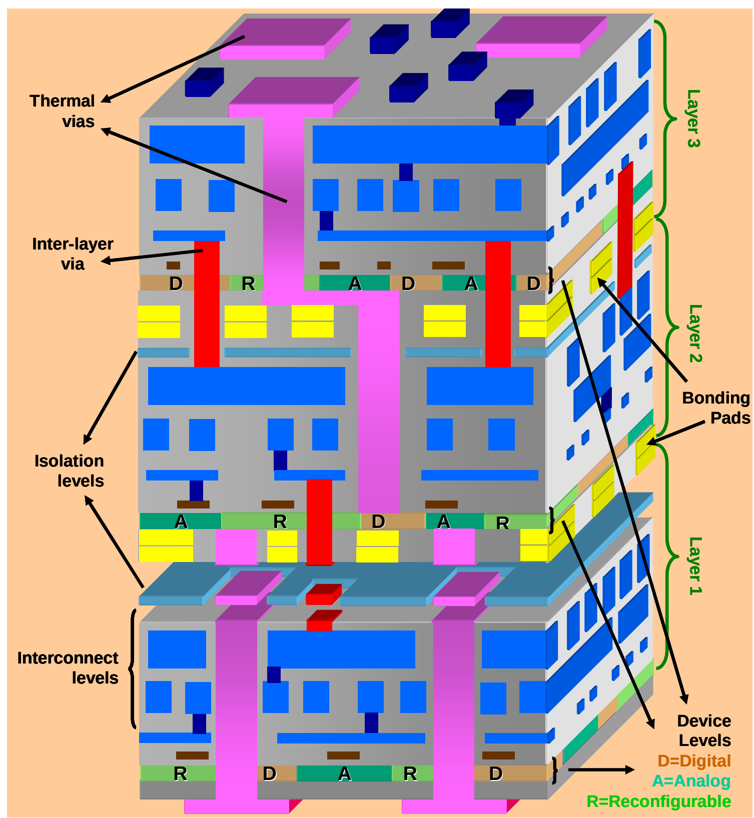

Figure 36: Illustration of a 3-D circuit employing advanced functionality in each layer and reducing the length of critical signal paths (the square area illustrated would be comparable in dimension to the cross-section of a human hair).

DARPA is tackling one of the most important roadblocks to increasing chip performance, heat dissipation. As the number of transistors on a chip and their clock frequency increase and the size of the transistors decrease, the waste heat generated rises sharply. Today, some chips radiate as much heat per square inch as a hotplate. As a result, chip clock speeds cannot be increased further, which threatens to break Moore's Law of continued performance improvement through transistor scaling and increasing clock speed.

DARPA is pursuing three ways to push through the heat dissipation roadblock. First, an entirely new type of transistor, called a tunneling transistor, is being investigated that would operate at lower voltages – ¼ volt instead of today's 1 volt – thereby greatly reducing the active heat dissipation, which is proportional to the square of the voltage. Second, efforts are underway to reduce the standby heat dissipated when a transistor is nominally "off" by using nanoelectromechanical switches to physically disconnect, or "unplug" a transistor when it is off, preventing leakage current that generates waste heat. Third, researchers are working to reduce the heat dissipated by the interconnects, or wires, that connect the active devices within a chip by replacing some of the longer metal wires with optical interconnects, which would generate far less heat, while greatly improving data transfer speed.

And in the longer term, non-silicon electronics will play an increasing role in the advance of microelectronics. Alternatives to traditional silicon chips can provide key advantages to military systems, including greatly enhanced operating speeds, the ability to handle enormous power loads, or dramatically reducing power consumption. DARPA's wide bandgap semiconductor research has produced transistors that offer speed and power performance far exceeding silicon devices. Silicon carbide power transistors allow shipboard power converters to operate at high voltage and high switching rates, saving tons of copper and iron weight required by old-fashioned transformers. For higher speed applications, gallium nitride can amplify microwave signals with more than ten times the power density of gallium arsenide, another non-silicon technology which already dominates these applications. Gallium nitride has the potential to realize transistors with useful voltage swings more than ten times greater than a silicon MOSFET of the same physical size, while simultaneously achieving speeds almost four times as fast.

Working with the Navy

DARPA maintains relationships with Naval staff through the Operational Liaison program, and with senior leadership through regular information exchanges. These latter include recent visits between the Director and the Secretary of the Navy, Chief of Naval Operations, Combatant Commanders, and the Chief of Naval Research. DARPA integrates these important inputs with those from other senior Interagency leadership to create synergy for Naval programs, and responsive support to the warfighter.

Memoranda of Agreement (MOAs) established between DARPA and Naval leadership maintain commitment to future revolutionary technologies. Recent MOAs include use of software agents to find suspicious patterns in high-interest shipping; new, corrosion-resistant materials; revolutionary learning aids; language translation and exploitation; micro air vehicles; augmented cognition capabilities for next generation Navy Marine Corps Intranet; and revolutionary radar with the ability to maintain persistent surveillance on targets of interest in challenging environments. Work continues with the Navy in efforts to dramatically reduce costs and increase capabilities in aircraft and ship construction programs.

For the future, Naval challenges of sophisticated missiles, electronic warfare, and antisubmarine warfare will be priorities, along with intelligent management of information resources. Efforts are underway in long-range missile countermeasures, self-forming communication networks, and extremely capable autonomous vehicles – and delivering the right information to the right decision-maker at the right time.

Photonics: Increasingly, vast amounts of information are being moved between computers, often using light to carry it. DARPA has pioneered development of new photonic components, such as optical wavelength converters, optical switches, optical waveform generators, and optical buffers, that were developed under the Data in the Optical Domain Network (DOD-N) program. DOD-N has, for the first time, shown a path to an optical network that eliminates electrical-to-optical-to-electrical data conversion at each data router, thereby increasing the projected network data throughput by over a factor of 10. Combined with new network management strategies that dramatically reduced the amount of buffer memory required at each network node, DOD-N will enable new optical networks that can meet the growing DoD need for bandwidth, while also minimizing latency.

Microelectromechanical Systems (MEMS): Miniaturizing mechanical, thermal and chemical devices often yields dramatic increases in performance versus their conventional, bulky counterparts. Microscale chemical and biological sensors are being developed that yield lower power and higher performance, as seen in faster response times, lower false alarm rates, and higher probability of detection. The Micro Gas Analyzer program is shrinking a lab bench of equipment for analysis of toxic chemicals down to a few cubic centimeters, allowing for person-or UAV-carried applications that will revolutionize our awareness of the chemical and biological battlespaces.

Combined Systems-on-a-Chip: The Navigation-Grade MEMS Inertial Measurement Unit program is developing tiny, low-power, navigation sensors capable of achieving performance comparable to GPS in settings where GPS is unavailable (e.g., caves, underwater) or denied by an enemy. This will enable precision navigation of small platforms, including individual troops, unmanned (micro) air vehicles, unmanned underwater vehicles, and even tiny (e.g., insect-sized) robots. This program will revolutionize our ability to navigate in places we never could before and in places where adversaries would deny GPS, bringing the equivalent of hundreds of pounds of precision equipment down to systems that could fit in a wristwatch.

3.9.6. Information Technology

The DoD is undergoing a transformation within network-centric operations – to turn information superiority into combat power. DARPA's information technology programs are building on both traditional and revolutionary computing environments to provide the kind of secure, robust, efficient, and versatile computing foundation that our network-centric future requires. DARPA will create radical new computing capabilities to make the commander and the warfighter more effective in the field.

DARPA's work in information technology is closely intertwined with its strategic thrust in Increasing the Tooth to Tail Ratio. It is a core technology that supports advanced military capabilities in the post-2010 timeframe with processing performance in excess of one quintillion (10^{18}) operations (floating point, fixed point or data movement) per second. Such "extreme computing" systems will be critical if the United States is to maintain supercomputer-parity with competing peer and adversary nations. Given the importance of supercomputing for the design of advanced weapons systems and for command and control it is imperative for the United States to remain at the forefront in this critical technology area.

Also in this area, DARPA's Computer Science Study Group (CSSG) program selects a group of extremely talented early-career academic computer scientists for a program that combines support for their current innovative research with educating them on DoD's need. CSSG then challenges them to use the knowledge they've gained to compete for grants of up to $500,000 to conduct basic research of interest to DoD. Each group is typically about a dozen academics who obtain Secret security clearances and learn about DoD facilities.

3.9.7. Mathematics

DARPA's mathematics program develops new mathematical tools for a broad continuum of DoD missions. The program is rooted in the tenet that DoD needs are best addressed by integrated teams of mathematicians and subject matter experts. This enables the rapid exploitation of new mathematical techniques to create novel technologies, as well as translating technological needs into research problems for the mathematics community.

Current program themes include topological and geometric methods, inverse methods, multiresolution analysis, representations, and computation that are applied to design and control complex systems, extract knowledge from data, forecast and assess risk, develop algorithms, and perform efficient computations. These techniques underlay key Defense applications such as signal and image processing; understanding biology, materials, and sensor data, design, and deployment; and design of complex systems.

For example, the Topological Data Analysis program (Figure 37) is developing mathematical concepts and techniques to determine the fundamental structure of massive data sets along with the tools to exploit that knowledge. The result will be easy-to-use algorithms that find and display hidden properties of massive data sets and allow greater and faster understanding of the phenomena they represent. Recent program results include key insights in such diverse fields as images, material science, cancer biology, virus evolution and medical diagnostics. Distinguishing high-dimensional patterns in the statistics of natural images is leading to the development of a novel, non-linear, compression scheme that will revolutionize the way that images are analyzed. Similarly, TDA methods will transform the way that doctors triage patients, through construction of non-linear, non-invasive medical statistics to assess patients in intensive and critical care situations.

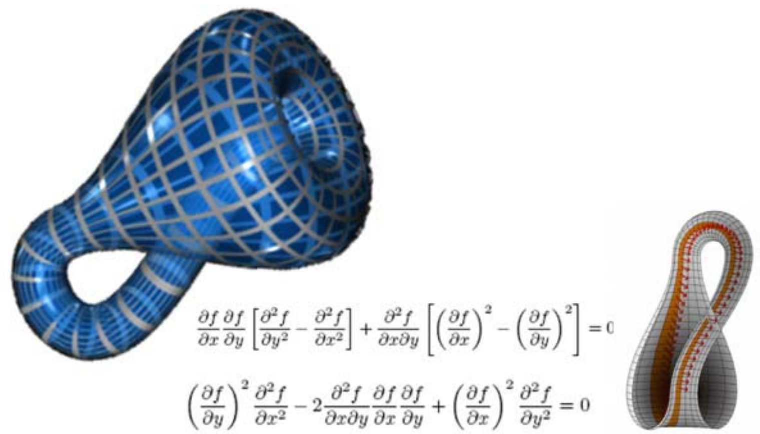

Figure 37: DARPA’s Topological Data Analysis program seeks the fundamental structure of massive data sets and is developing the tools to exploit that knowledge.

By promoting interaction among the most creative thinkers in mathematics with leaders in disparate fields such as physics, biology, material sciences, and engineering, the programs seek to understand and intertwine fundamental mathematics with applications for the full spectrum of DoD needs. Today’s applied mathematics and computational research programs help achieve cutting-edge technical superiority, while the basic mathematical research programs are securing the foundation for advanced science and technology programs.

3.9.8. Manufacturing Science and Technology

The DoD requires a continuous supply of critical, defense-specific materiel and systems. To ensure reliable, robust, and cost-effective access to these items, manufacturing technologies that can meet DoD’s needs must be available in the DoD industrial base.

DARPA’s Disruptive Manufacturing Technologies (DMT) program is developing manufacturing technologies and processes to provide significant and pervasive cost savings for multiple platforms or systems, and/or decreases in manufacturing cycle time for components for existing and future military procurements. DMT is piloting new manufacturing process initiatives in microwave electronics, adaptive software development, and advanced materials, with a focus on producing microwave amplifiers for electronic and information warfare, radar, and communication systems; designing and producing adaptive software-intensive systems; and revolutionary new, faster, and lower-cost methods for producing polymer matrix composites for aerospace components, superalloy high-strength blades that power aircraft turbine engines, and boron carbide inserts for body armor.

3.9.9. Lasers

Lasers are a core technology that has been important to the Department for over 40 years. Lasers have multiple military uses, from sensing to communication to electronic warfare to target designation. Since the technology was first demonstrated, DoD has maintained a steady interest in High-Energy Laser Systems for a wide range of speed-of-light weapon applications. Starting in the early 1960s, DARPA has been involved in lasers and laser technology development for DoD, and continues its work today in this crucial area.

For example, DARPA is currently working on lasers to arm platforms. The High Energy Liquid Laser Area Defense System (HELLADS) program is developing a high-energy laser weapon system (~150 kilowatt) with an order-of-magnitude reduction in weight compared to existing laser systems. With a weight goal of less than five kilograms per kilowatt, HELLADS would transform operations and provide a tremendous advantage to U.S. forces, such as use on tactical aircraft systems for effective self-defense against even the most advanced surface-to-air missiles. If successful, HELLADS will lead to a truly practical, small-size, low-weight tactical laser weapon. This kind of weapon will transform offensive and defensive operations, and provide a tremendous advantage to U.S. forces.

Advanced semiconductor device concepts are also opening new systems opportunities. For example, the Super High Efficiency Diode Sources program has broken new ground in semiconductor diode lasers that will be used as the front end pump source for tactical high power laser systems. The program has more than doubled the efficiency of the laser diodes, with a corresponding reduction in waste heat. This increase in efficiency will dramatically reduce the waste heat and power consumption in tactical laser systems, directly translating to improved mission performance.

4. Programs and Budget Supporting DARPA's Strategic Thrusts

Figure 38 presents an overview of which Budget Program Elements (PE's) and Budget Project Numbers[10] principally fund each of DARPA's Strategic Thrusts. Details on individual programs can then be found by reading those sections of DARPA's Budget Estimates[11]. The table also shows the principal DARPA offices supporting each area; please refer to the websites of those offices for information on their programs.

Strategic Thrusts			
Strategic Thrust	**Principal Office(s)**	**Principal Budget Program Elements**	**Principal Budget Project(s)**
Detection, Precision ID, Tracking, and Destruction of Elusive Targets	IPTO STO	Command, Control and Communications Systems (0603760E)	CCC-01
		Network-Centric Warfare Technology (0603766E)	NET-01, NET-02
		Sensor Technology (0603767E)	SEN-01, SEN-02
		Guidance Technology (0603768E)	GT-01
Robust, Secure, Self-Forming Networks	IPTO STO	Cyber Security Initiative (0305103E)	CYB-01
		Information and Communications Technology (0602303E)	IT-03
		Command, Control and Communications Systems (0603760E)	CCC-02
Urban Area Operations	DSO IPTO STO TTO	Tactical Technology (0602702E)	TT-04; TT-06; TT-13
		Command, Control and Communications Systems (0603760E)	CCC-01
		Network-Centric Warfare Technology (0603766E)	NET-01
		Sensor Technology (0603767E)	SEN-01; SEN-02
Advanced Manned and Unmanned Systems	TTO STO	Tactical Technology (0602702E)	TT-03; TT-07
		Advanced Aerospace Systems (0603286E)	AIR-01
		Network-Centric Warfare Technology (0603766E)	NET-02
Detection, Characterization, and Assessment of Underground Structures	STO	Sensor Technology (0603767E)	SEN-01
Space	STO TTO	Space Programs and Technology (0603287E)	SPC-01
Increasing the Tooth to Tail Ratio	IPTO	Information and Communications Technology (0602303E)	IT-02, IT-04
		Cognitive Computing Systems (0602304E)	COG-02; COG-03
Bio-Revolution	DSO STO	Biological Warfare Defense (0602383E)	BW-01
		Materials and Biological Technology (0602715E)	MBT-02

(Table continued on next page)

Figure 38: DARPA's Strategic Thrusts, the principal offices supporting those thrusts, and the Program Element and Project numbers in the Descriptive Summaries for FY 2009.

[10] Budget Project Numbers refer to a subset of programs grouped together under each Program Element to provide a somewhat finer level of financial detail.

[11] Available online at www.darpa.mil/budget.html.

Strategic Thrusts (*continued*)			
Strategic Thrust	**Principal Office(s)**	**Principal Budget Program Elements**	**Principal Budget Project(s)**
Core Technologies			
Quantum Science and Technology	DSO MTO STO	Defense Research Sciences (0601101E)	ES-01; MS-01
		Electronic Technology (0602716E)	ELT-01
Bio-Info-Micro	DSO	Defense Research Sciences (0601101E)	BLS-01; MS-01
Materials	DSO	Defense Research Sciences (0601101E)	MS-01
		Materials and Biological Technology (0602715E)	MBT-01
Power and Energy	DSO STO	Materials and Biological Technology (0602715E)	MBT-01
Microsystems	MTO DSO	Defense Research Sciences (0601101E)	ES-01
		Electronics Technology (0602716E)	ELT-01
		Advanced Electronics Technologies (0603739E)	MT-12; MT-15
Information Technology	IPTO MTO DSO	Defense Research Sciences (0601101E)	CCS-02
Mathematics	DSO	Defense Research Sciences (0601101E)	CCS-02
		Tactical Technology (0602702E)	TT-06
Manufacturing Science and Technology	MTO	Electronic Technology (0602716E)	ELT-01
		Advanced Electronics Technology (0603739E)	MT-15
Lasers	TTO MTO	Tactical Technology (0602702E)	TT-06

5. Additional Information

5.1. General

Additional information on DARPA's offices and programs is available at www.darpa.mil. In-depth information is contained in DARPA's budget requests at www.darpa.mil/budget.html.

Information on current DARPA solicitations may be found at www.darpa.mil/solicitations.html. Of special interest to small businesses may be DARPA's Small Business Innovation Research (SBIR) program; more information may be found at www.darpa.mil/sbir/.

The DARPA Director's March 13, 2008 testimony to the Subcommittee on Terrorism, Unconventional Threats and Capabilities of the House Armed Services Committee may be found at www.darpa.mil/testimony/hasc3-13-08.pdf.

DARPA program news releases can be found at www.darpa.mil/newsroom.html.

5.2. Special Assistant for Technology Transition

DARPA has a permanent full-time person focused on promoting technology transition. To do so, he works closely with the Operational Liaisons and Agency Representatives, who rotate in and out of DARPA.

Special Assistant for Technology Transition .... Mr. Chris Earl (571) 218-4425
Chris.Earl@darpa.mil

5.3. DARPA Operational Liaisons and Representatives

DARPA's Operational Liaisons serve as points of contact for the Services. Service representatives with technical questions or needs are encouraged to contact the liaisons or a DARPA program manager working the area closest to a particular area of interest.

Army: .... COL Valerie Jircitano-Jacocks (571) 218-4349
Valerie.Jacocks@darpa.mil

Navy: .... CAPT John Murphy, (571) 218-4590
John.Murphy@darpa.mil

Air Force: .... Col William Reese (703) 696-6619
William.Reese@darpa.mil

Marines: .... Col Thomas C. Moore (571) 218-4387
Thomas.Moore@darpa.mil

National Geospatial-Intelligence Agency .... Mr. Fred Schnarre (571) 218-4597
Fred.Schnarre@darpa.mil

The operational liaisons may also be contacted via SIPRNET at [username]@darpa.smil.mil.

In addition, DARPA has a representative located at the U.S. Special Operations Command:

USSOCOM .... Ms. Kathy MacDonald (813) 828-9366
Kathy.Macdonald@darpa.mil